This thesis is based on original research embracing a comparative analysis of the physical properties of Temporary Baseplate Materials and is submitted in accordance with the requirements of the New By-Laws, in support of candidature for the degree of Master of Dental Surgery.

I. Kincher G.

ACKNOWLEDGEMENTS

This research project was carried out at the Dental School, University of Sydney, New South Wales, Australia.

Thanks are due to Professor C. H. Graham, Head of the Department of Prosthetic Dentistry, for the opportunity made available to me and for his encouragement during this research project.

To Dr. R. G. Earnshaw, Reader in Prosthetic Dentistry, who supervised this work, I wish to express sincere appreciation for his constant interest and invaluable assistance at all times, without which this thesis would not have reached completion.

I also wish to acknowledge the advice and help of Mr. E. Bevan, Senior Lecturer in Prosthetic Dentistry, and the painstaking technical assistance of Mr. B. Mercer.

The draft was typed jointly by Miss Sylvia Blaut and Miss Marilyn Kellett, and the final manuscript was typed by Miss Kellett. I wish to express my thanks for this help.

Faculty of Dentistry,

University of Sydney,

New South Wales,

Australia.

THE PHYSICAL PROPERTIES

OF

TEMPORARY BASEPLATE

MATERIALS

INDEX

		Page
CHAPTER 1.		1
1.1.	Introduction	1
1.2.	The present problem	3
1.3.	Materials tested	4
CHAPTER 2.	THE SHELLAC MATERIALS	6
2.1.	Composition	6
2.2.	Development of testing methods	8
2.2.1.	Transverse strength and rigidity	
2.2.2.	Flow	
2.2.3.	Dimensional stability	
2.2.4.	Reproduction of surface detail	
2.3.	Apparatus	35
2.3.1.	Transverse strength and rigidity	
2.3.2.	Flow	
2.3.3.	Dimensional stability	
2.3.4.	Reproduction of surface detail	
2.4.	Experimental method	46
2.4.1.	Transverse strength and rigidity	
2.4.2.	Flow	
2.4.3.	Dimensional stability	
2.4.4.	Reproduction of surface detail	
2.5.	Results	51
2.5.1.	Transverse strength and rigidity	

Page

2.5.2. Flow

2.5.3. Dimensional stability

2.5.4. Reproduction of surface detail

2.6. Discussion 71

2.6.1. Transverse strength and rigidity

2.6.2. Flow

2.6.3. Dimensional stability

2.6.4. Reproduction of surface detail

CHAPTER 3. THE THERMO-SOFTENING SYNTHETIC RESIN MATERIALS 80

3.1. Introduction 80

3.2. Development of testing methods 81

3.3. Apparatus 83

3.4. Experimental method 83

3.4.1. Transverse strength and rigidity

3.4.2. Flow

3.4.3. Dimensional stability

3.4.4. Reproduction of surface detail

3.5. Results 85

3.5.1. Transverse strength and rigidity

3.5.2. Flow

3.5.3. Dimensional stability

3.5.4. Reproduction of surface detail

3.6. Discussion 93

3.6.1. Transverse strength and rigidity

Page

3.6.2. Flow

3.6.3. Dimensional stability

3.6.4. Reproduction of surface detail

CHAPTER 4. THE COLD-CURED ACRYLIC RESIN MATERIALS 96

4.1. Introduction 96

4.1.1. Preliminary tests

4.1.2. Doughing time

4.1.3. Working time

4.1.4. Hardening time

4.1.5. Application

4.2. Development of testing methods 106

4.2.1. Transverse strength and rigidity

4.2.2. Flow

4.2.3. Dimensional stability

4.2.4. Reproduction of surface detail

4.3. Apparatus 117

4.3.1. Transverse strength and rigidity

4.3.2. Flow

4.3.3. Dimensional stability

4.3.4. Reproduction of surface detail

4.4. Experimental method 122

4.4.1. Transverse strength and rigidity

4.4.2. Flow

4.4.3. Dimensional stability

		Page
4.4.4.	Reproduction of surface detail	
4.5.	Results	126
4.5.1.	Transverse strength and rigidity	
4.5.2.	Flow	
4.5.3.	Dimensional stability	
4.5.4.	Reproduction of surface detail	
4.6.	Discussion	152
4.6.1.	Transverse strength and rigidity	
4.6.2.	Flow	
4.6.3.	Dimensional stability	
4.6.4.	Reproduction of surface detail	
CHAPTER 5.	COMPARISON OF RESULTS	160
5.1.	Introduction	160
5.2.	Comparison	160
5.2.1.	Transverse strength and rigidity	
5.2.2.	Flow	
5.2.3.	Dimensional stability	
5.2.4.	Reproduction of surface detail	
CHAPTER 6.	CLINICAL SIGNIFICANCE	168
6.1.	Introduction	168
6.2.	Results	170
6.3.	Discussion	172
CHAPTER 7.	CONCLUSIONS	176
	REFERENCES	178

LIST OF ILLUSTRATIONS

		Page
2-1.	Transverse testing machine.	9
2-2.	Third order lever system.	14
2-3.	Second order lever system.	14
2-4.	Loading apparatus (prototype).	15
2-5.	Flow testing machine.	19
2-6.	Mould for flow specimen preparation.	20
2-7.	Oven.	22
2-8.	Water bath.	22
2-9.	Dial gauge comparator.	25
2-10.	Continuous warpage measurements.	28
2-11.	Travelling microscope.	29
2-12.	Baseplate showing flow due to its own weight.	31
2-13.	Die, counter-die and baseplate.	34
2-14.	Brass die.	34
2-15.	(a) New transverse testing machine.	38
	(b) Disposition of water bath.	39
	(c) Ball-races supporting plunger.	40
	(d) Gear-box, motor and carriage (front view).	41
	(e) Gear-box and motor (from above).	41
	(f) Carriage (from below).	42
2-16.	Baseplate and cast on dial gauge platform.	45
2-17.	Load-deflection graph, Impo Brown.	54
2-18.	" " " , Impo Pink.	54

		Page
2-19.	Load-deflection graph, Ainsworth Plastic Aluminium.	55
2-20.	" " " , Ainsworth Brown.	55
2-21.	" " " , Ainsworth Pink.	56
2-22.	" " " , Ainsworth Aluminium Injection Moulded.	56
2-23.	" " " , Alston Maroon.	57
2-24.	" " " , Ash Pink.	57
2-25.	" " " , Ash Metallized.	58
2-26.	" " " , Yellow-trays.	58
2-27.	" " " , Cavex.	59
2-28.	Flow: Ash Pink.	62
2-29.	Relative flow of the shellac materials.	62
2-30.	Series of flow specimens.	63
2-31.	Histogram, Flow tests in water.	64
2-32.	" , Flow tests in air.	65
2-33.	Reproduction of surface detail: Ainsworth Pink.	70
2-34.	Histogram, Dimensional stability tests (softening in water).	75
2-35.	" , Dimensional stability tests (softening in air).	76
3-1.	Load-deflection graph, Keba-Plast.	87
3-2.	" " " , Heko-Werk.	87
3-3.	" " " , Bayer.	88
3-4.	Keba-Plast specimen deflecting through full range of testing machine.	89

		Page
4-1.	Temperature evolution graphs.	102
4-2.	Mould for transverse strength specimens.	108
4-3.	Adapting the resin within the mould.	109
4-4.	Mould: preparing specimens of specification dimensions.	113
4-5.	Jigs.	113
4-6.	Specimen showing permanent deformation after transverse testing.	116
4-7.	Die and counter-die.	116
4-8.	Cast and baseplate.	121
4-9. to 4-12.	Load-deflection graphs; specimens tested one hour after mixing.	136
4-13. to 4-16.	Load-deflection graphs; specimens tested at 21°C in air, following 24 hours' storage.	138
4-17. to 4-20.	Load-deflection graphs; specimens tested at 37°C in water, following 24 hours' storage.	140
4-21. to 4-24.	Load-deflection graphs; specimens tested at 21°C in air, following 72 hours' storage.	142
4-25. to 4-28.	Load-deflection graphs; specimens tested at 37°C in water, following 72 hours' storage.	144
4-29. to 4-33.	Load-deflection graphs; specimens tested at 37°C in water, following storage for one week.	146
5-1.	Baseplates: reproduction of surface detail for each group of materials.	167
6-1.	Baseplate and cast showing warpage.	174

CHAPTER 1

1.1. INTRODUCTION.

Temporary baseplates play an important part in the construction of most full and partial dentures, and clinicians rely on the strength and stability of these materials during important phases of denture construction. Yet little information is available concerning the properties of temporary baseplates and no reference is made to them in current Dental Materials text books.

It is common experience that shellac materials distort following adaptation to a cast. This occurs at room temperature, occurs more rapidly at higher temperatures such as mouth temperature, and is manifested by a warpage away from the cast in the peripheral areas and in the case of the maxillary baseplate, away from the palatal area also. Forces exerted on the baseplate during clinical use could lead to plastic deformation and thus exaggerate warpage.

It has been said that registrations are no more accurate than the bases used in their execution[1]. House[2] stated: "Almost universal inaccuracy in the art of making dentures is evident in the bite plate used for registering maxillary relations." Keyes[3] said, in effect, that one of the main reasons for faulty centric occlusion in the finished

denture is the failure to use properly stabilised baseplates. Zuckerman[4] stated with reference to shellac: "Conventional baseplate material adapted to fit a perfect master cast, is at best a poor foundation for the precise measurements needed for proper occlusion and the patient's comfort".

Some workers have been a little more ambitious, and have suggested possible alternatives for the shellac materials. Wright[5] and Swensen[6] suggested the use of vulcanite baseplates, while Trapozzano[7] preferred lining a shellac baseplate, which had been adapted to a cast, with tracing stick compound. Ringsdorf[8] suggested lining a formed baseplate with cold-cured acrylic resin and stated that subsequent baseplates "are surprisingly strong and will not warp". Elder[9] gave a technique for using cold-cured resin as a trial baseplate material and recommended the "sprinkle-on method" as described by McCracken[10], whereby the baseplate is built up in stages on the cast, by adding monomer and then sprinkling polymer over the wetted surface to absorb the monomer. More recently, Terry and Wahlberg[11] suggested vacuum moulding baseplates using shellac and cold-cured acrylic resin. A simple vacuum apparatus allowed rapid and good adaptation of the baseplate material to a cast, as indicated by tissue contour tracings of the baseplates and the cast immediately following moulding. Unfortunately, warpage after a time interval was not assessed.

Vacuum moulding has also been used with thermo-softening plastic materials such as polystyrene, to overcome the difficulties involved in adaptation for use as baseplates or impression trays. These materials present problems in moulding intimately to a cast and in America a vacuum adaptor, "Acra-Vac" is available and is recommended for use with polystyrene. The apparatus is supplied by the Jectron Company and incorporates a heating mechanism to render the polystyrene sheet uniformly plastic before vacuum moulding.

1.2. THE PRESENT PROBLEM.

It can be seen that a few authors have expressed dissatisfaction with shellac baseplate materials. However, criticisms and suggestions have been entirely subjective and no effort has been made to reveal objectively the relative merits of the three groups of materials: shellac, cold-cured acrylic resins and thermo-softening synthetic resin materials. It was thought that a knowledge of the physical properties of these materials would allow the best results to be obtained clinically. A comparison of the following physical properties would allow an objective assessment of the clinical suitability of the three types of baseplate materials: strength and rigidity; flow; dimensional stability following moulding; and reproduction of surface detail.

It was with concern for these problems that this investigation was carried out.

1.3. THE MATERIALS TESTED.

The materials tested are listed in Table 1-1, together with their manufacturers. The batch-numbers are also listed wherever possible.

TABLE 1-1

	MATERIAL	MANUFACTURER	BATCH NO.
	Shellac Materials:		
1.	Impo Brown	Ainsworth Dental Co. Australia.	40433
2.	Impo Pink	"	40514 40816
3.	Ainsworth Plastic Aluminium Tray Blanks	"	844 40644
4.	Ainsworth Brown (Injection moulded)	"	50408
5.	Ainsworth Pink (Injection moulded)	"	50457
6.	Ainsworth Aluminium (Injection moulded)	"	50623
7.	Alston Maroon	Dental Manufacturing Co. England.	
8.	Ash Pink	Amalgamated Dental Trade Distributors, England.	BE 31
9.	Ash Metallized Special Tray Forms	"	DG4 DJ
10.	Yellow-trays	Keur & Sneltjes Dental Manufacturing Co. Holland.	288 042
11.	Cavex	"	104 263

TABLE 1-1 (Contd.)

Thermo-softening synthetic resin materials:

1.	Keba-Plast	A. Kettenbach, Germany.	
2.	Heko-Werk	Heko-Werk, Germany.	
3.	Bayer	Bayer AG, Germany.	

Cold-cured acrylic resin materials:

1.	Tray Plastic	Coe Laboratories, Inc. U.S.A.	
2.	Traybase	Dental Fillings Ltd.	Powder ZFO ASV Liquid -
3.	Trayresin	L.O. Caulk Co. U.S.A.	Powder 35148 Liquid 305948
4.	Formatray	Kerr Manufacturing Co. U.S.A.	Powder 0844 F007 Liquid 0843 E617

CHAPTER 2

SHELLAC MATERIALS

2.1. COMPOSITION.

Shellac baseplate materials are composed mainly of shellac, together with fillers, a form of plasticiser and often colouring agents.

Shellac is a naturally occurring resin with a melting point of 80°C. It is secreted by insects (Taccifer Lacca) which are parasitic to certain Indian trees of the genus Acacia. The branches, upon which the insects feed, are heated and the resin can be collected. In its natural state shellac is an orange-brown colour; a white variety can be obtained by bleaching the natural resin with sodium hypochlorite. Either can be used in making baseplates and the former causes the baseplate to have a typical brown colour. When white shellac is used, colouring agents in the form of oil soluble dyes are added in small amounts, to produce the familiar pink colour. It is not uncommon to have a combination of white and brown shellac in the baseplate materials.

The filler is commonly a mixture of powdered talc and mica and each has a different effect on the resulting physical properties of the material. Powdered talc is hydrated magnesium silicate and mica is a complex aluminium silicate. Mica causes

a far greater increase in strength than talc in similar quantities, due to its toughness and plate-like crystalline structure; the finer particle size of the talc improves the ability of the material to reproduce detail. Finely powdered aluminium can also be used as a filler in combination with talc and mica, and the baseplates then have a silver colour. Dyes can still be added, for example to produce a bronze colour.

Stearin and stearic acid are added as the plasticiser and the latter has a boiling point of 69°C. Overheating a shellac baseplate can have an adverse effect on its properties. Overheating in air at 70°C causes boiling of the stearic acid plasticiser accompanied by bubbling of the surface of the shellac. Further heating causes a condensation polymerisation reaction with water being split off. Heating at 100°C for 5 to 10 min can remove all the plasticiser, superimposed upon this condensation polymerisation, and the material then cannot be softened; instead, further heating will cause it to burn. The condensation polymerisation reaction is a reversible reaction, and water can be restored to the material by autoclaving for a short time.

Overheating in water causes the loss of the plasticiser by leaching, and a resulting decrease in plasticity also.

The shellac materials tested in this investigation are listed in Table 1-1, together with the names of the

manufacturers.

2.2. DEVELOPMENT OF TESTING METHODS.

2.2.1. Transverse Strength and Rigidity:

A transverse strength testing machine for denture base resin is described in American[12], British[13] and Australian[14] Specifications. A testing machine of this design was used initially in an investigation of the transverse strength of shellac baseplate materials (Figure 2-1). It was during these tests that certain disadvantages of the apparatus became apparent, due to the low strength of the material under investigation.

The machine applies a load which increases incrementally rather than continuously; the specifications for denture base resins require the addition of load increments of 500 gm at a defined rate. With some of the specimens of baseplate materials tested, fracture occurred at loads of the order of 1500 gm, so that loading in increments of 500 gm does not allow an accurate determination of transverse strength.

The U.S. Federal Specification for dental baseplates[15] specifies continuous loading in a similar apparatus, by the pouring of lead shot into a bucket.

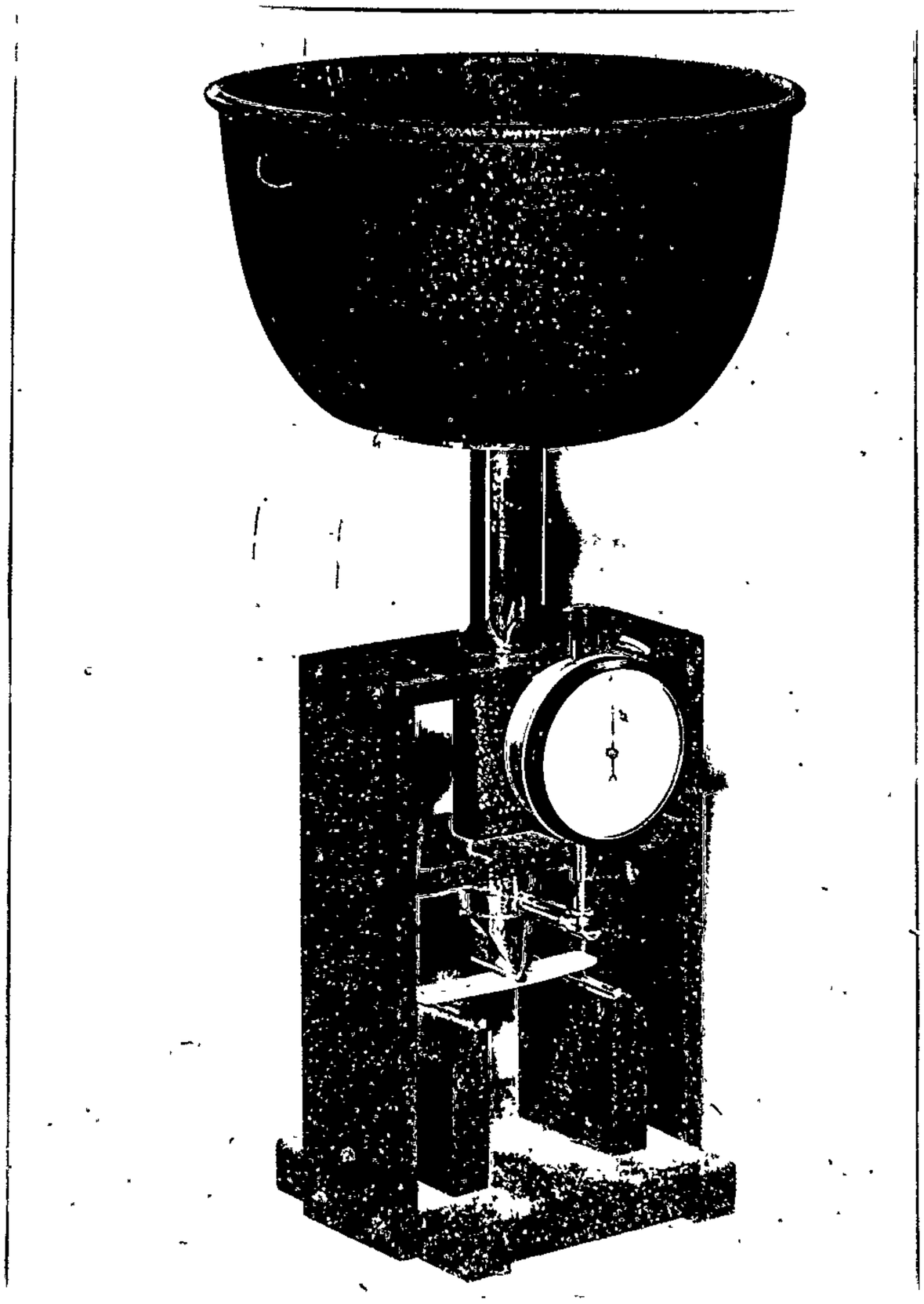


Figure 2-1

Transverse Testing Machine.

This is difficult to control and such a method makes it difficult to obtain simultaneous readings of load and deflection of the specimen.

Furthermore, the machine does not allow a reading of deflection to be taken at an initial zero load. This is a disadvantage with shellac baseplate specimens, where the initial load (of 500 gm in the case of the U.S. Federal Specification for dental baseplates) may be more than one third of the fracture load. An improved version of the standard transverse strength testing machine by Sweeney et al[16], allows an initial zero load, but maintains an incremental loading rate according to the specification for denture base resins.

It was therefore decided to develop a testing machine which would allow loading of the specimen at a uniform rate, starting from an initial zero load.

It was thought that adding lead shot to the bucket through a small orifice at the base of a reservoir could result in a constant rate of application of load. This was unsatisfactory, however, since binding in the orifice occurred. There was also a lack of uniformity in particle size of the lead shot with the larger particles tending to settle to the base of the reservoir, and thus to pass through first.

Mercury was used in place of the lead shot since it was thought that liquid flow would be uniform, and due to the high specific gravity of mercury, the amount used would be small in comparison with other liquids. A fine orifice was prepared in a glass tube and attached to the outlet of a funnel to which mercury was added. The diameter of the orifice was adjusted so that the mercury flowed at the required rate. After a short time, both the walls of the orifice and the connecting tube became covered with an oxide film. This resulted in a decrease in rate of flow and thus a decrease in loading rate, which was also unsatisfactory.

The disadvantages of using mercury could perhaps be overcome by using water and allowing it to pass through an orifice at the base of a reservoir. A constant level device was employed to maintain the water level in the reservoir, and thus the rate of flow. It was found that the rate of water flow was greatly influenced by small changes in water level height in the reservoir. The volume of water needed to fracture even the weakest shellac specimen was rather large, and the principle of levers was introduced, so as to reduce the actual volume of water added, without reducing the effective load on the specimen. A third-order lever system was used.

A beam was supported by a ball race fulcrum (A) on

a rigid column (Figure 2-2). A bucket was fixed to the end of the beam (B) to receive the water, and the beam and bucket were counterbalanced by a weight (C). The beam applied the load on a horizontal platform attached to the plunger of the testing machine (D).

The distance of the plunger (D) from the fulcrum (A) was one third the distance of the bucket (B) from the fulcrum, so that the volume of water added in a given time was one third the actual load exerted on the specimen.

Thus, the bucket was loaded until the specimen fractured, and then the amount of water in the bucket was weighed. This value was multiplied by three to give the fracture load of the specimen; readings of deflection were taken at intervals from the dial gauge.

Although this method gave encouraging results initially, it was found again that the rate of flow varied. The temperature within the laboratory fluctuated by $3^{o}C$ at the time, which caused a change in viscosity of water; this resulted in a variation in flow rate which was found to be approximately 200 cc/minute.

Due to the problems associated with fluid flow, it was decided to follow a purely mechanical method of loading, but to maintain the lever principle.

An electric motor was used to move a load along a beam at a constant rate, so that the force exerted on the specimen increased at the rate of 1500 gm/minute. The magnitude of the force exerted on the plunger, and thus on the specimen, was a function of the movable load (A), (Figure 2-3), and the distance (D) of the load from the fulcrum (B). This involved the use of a second-order lever system.

The loading apparatus is shown in Figure 2-4. The lever arm rotated about a knife-edge fulcrum (A) and load was transmitted to the plunger (B) through a ball-ended shaft (C) attached to the lever, bearing on a horizontal plate (D) on the plunger. This allowed the lever to move in an arc about the fulcrum, while the plunger moved vertically. A miniature electric motor (E) was mounted on a carriage (F), which supported two weights (G), one on either side of the lever arm. The speed of the motor was reduced by suitable gearing and the final drive gear moved the carriage along a threaded shaft at a constant rate. Frictional forces between carriage and beam were reduced by interposing six 0.25 inch ball bearings. These were housed in recesses in the base of the carriage, and supported the carriage in its movement along the beam. The beam was counterbalanced by a weight (H) so that the initial load was made up of the plunger of the basic testing machine and the attached horizontal plate (a

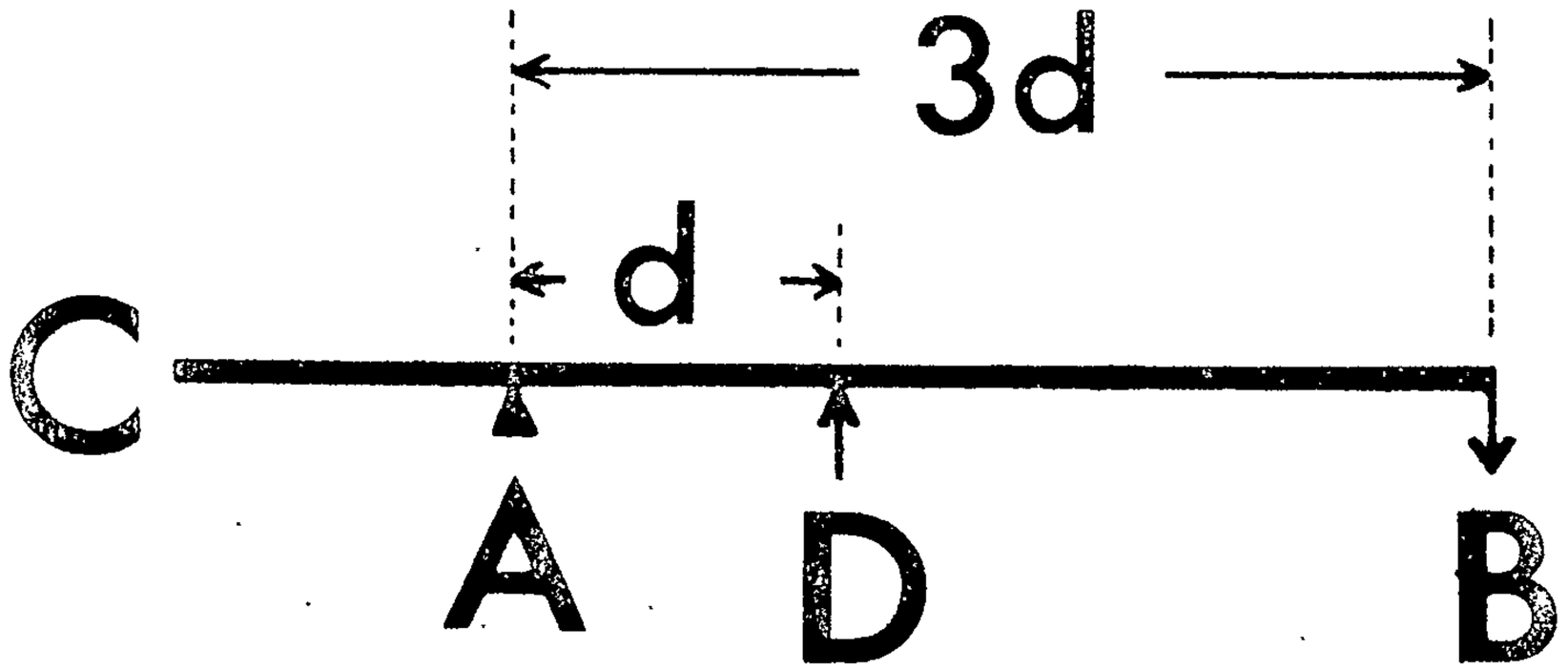


Figure 2-2

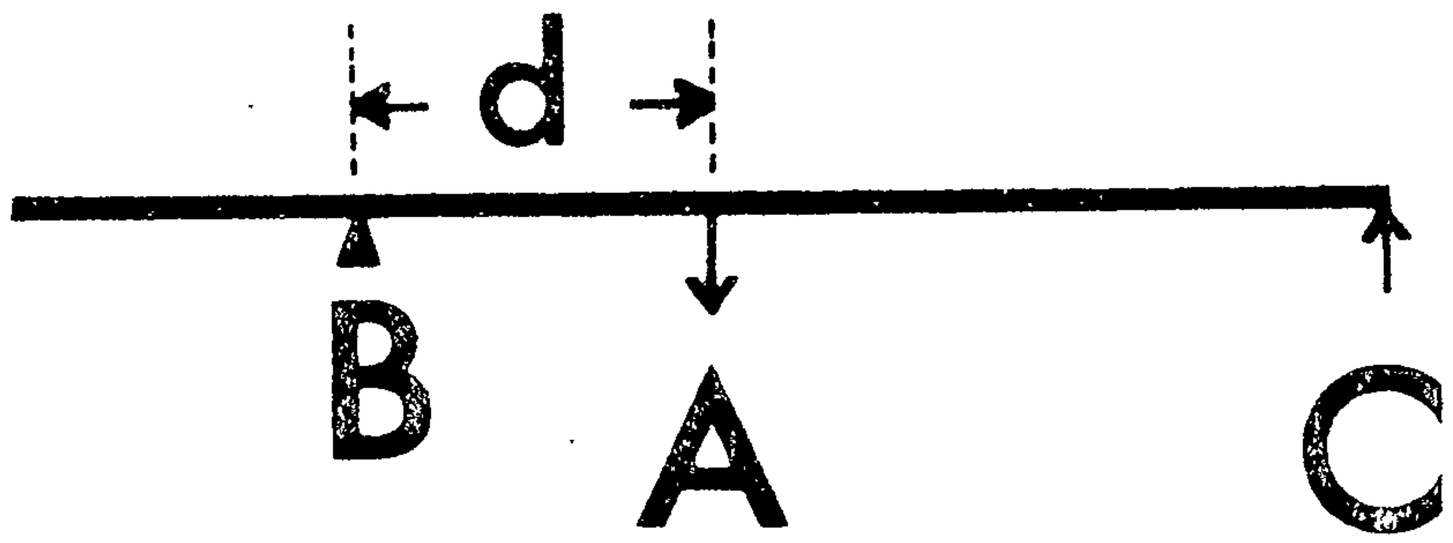


Figure 2-3

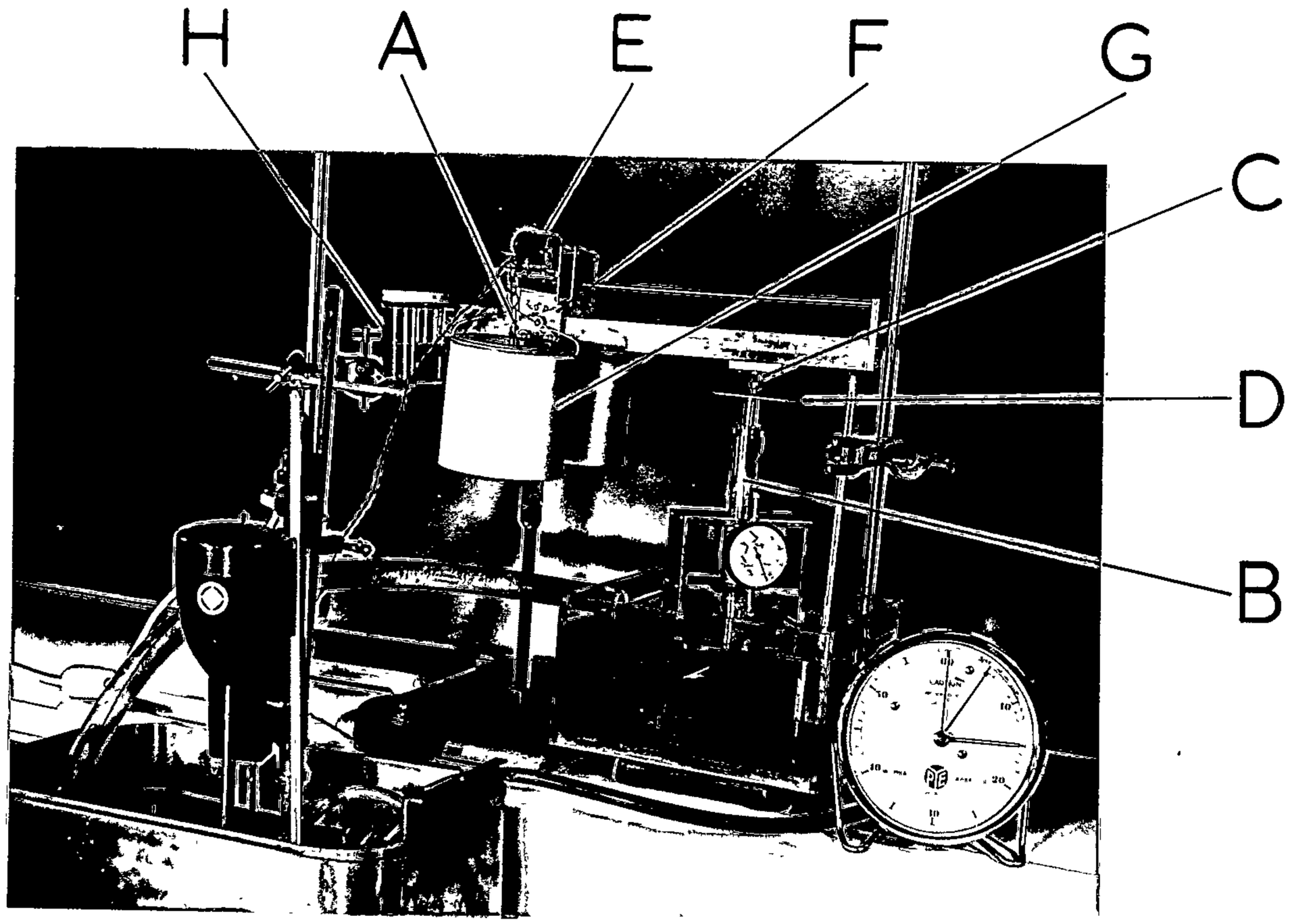


Figure 2-4

Loading apparatus (Prototype).

total of 500gm). Power for the motor was obtained from a two volt cell which was recharged weekly, to maintain a constant current source, and movement of the carriage was controlled by a foot switch.

This loading mechanism applied a load at a uniform rate to the specimen and confirmed that this principle of loading was satisfactory. Some of the tests whose results are reported in Section 2.5.1 were in fact made in this version of the machine. However, certain practical disadvantages became apparent:

(a) Despite the ball bearings recessed into the carriage base, frictional forces resisted carriage movement. It was considered that complete ball-race supports would be more satisfactory;

(b) the use of a knife-edge fulcrum resulted in lateral instability of the beam; (c) the carriage was unstable, since its centre of gravity was too high above the fulcrum; and (d) the test could not start at an initial zero load.

The apparatus was redesigned to overcome the problems mentioned previously. The plunger was coupled to the lever so that the entire loading system could be counterbalanced, to allow readings of deflection to start from an initial zero load. The lever rotated in ball-races at the fulcrum to overcome the instability of the knife-edge pivot originally used, and the carriage moved on ball-races to minimise frictional forces. In its final form, the machine is described in detail in Section 2.3.1.

2.2.2. Flow:

Plastic flow is a property possessed particularly by amorphous materials, which allows them to "continue to flow or deform under a given load without an increase in the magnitude of the applied force"[17]. Flow should be minimal at room temperature or mouth temperature, so that a baseplate will resist, without permanent deformation, forces applied during laboratory or clinical handling. On the other hand, flow should be high enough to permit easy moulding, at temperatures not too high to prevent manipulation with the fingers.

The flow test was similar to the American and Australian Specification tests for dental impression compound[18,19], and dental inlay casting wax[20,21], and also the Australian Specification for dental modelling wax[22]. The apparatus used was the one described in the above specifications (Figure 2-5), as was the mould used for preparation of specimens (Figure 2-6). In specimen preparation, the A.D.A. specification[18] requires the material to be softened by placing it in a crucible beneath a 250 watt infra-red lamp. A thermometer in the softened compound indicates the softening temperature, and the material is heated until sufficiently plastic to be poured into the mould. This method of softening was found to be unsatisfactory for the shellac materials, and use of an oven was far more precise. The oven

temperature was fixed at 90°C and the time at this temperature needed to render the baseplate material plastic, was determined. The softening time varied with each material and it was found that most materials when plastic could not be poured. Instead, a slight excess of plastic material was forced into the mould with a spatula, and then confined during cooling by means of a weighted glass slab, as defined in the A.D.A. specification for compound[18]. The specimens so formed were cylinders, 10 mm in diameter and approximately 6 mm in height.

Flow tests were carried out at 21°C in air, at 37°C in water, and at 60, 70 and 80°C both in air and in water. The tests at elevated temperatures in air were carried out in a laboratory oven (Figure 2-7), with an inner glass door containing two arm holes. This allowed the outer door of the oven to be opened and a specimen positioned under the flow testing machine, without a change in temperature of the oven. This was confirmed by embedding the hot junction of a 34 gauge chromel/alumel thermocouple in the centre of a specimen; the cold junction was maintained at 0°C by immersion in melting ice in a Dewar flask and the e.m.f. of the couple was measured by a null method, using a Cambridge potentiometric recorder. The specimen with the embedded thermocouple was positioned in the oven beneath the platen of the testing machine and the outer door opened for 10, 15 and 20 second intervals and the temperature change noted. It was found

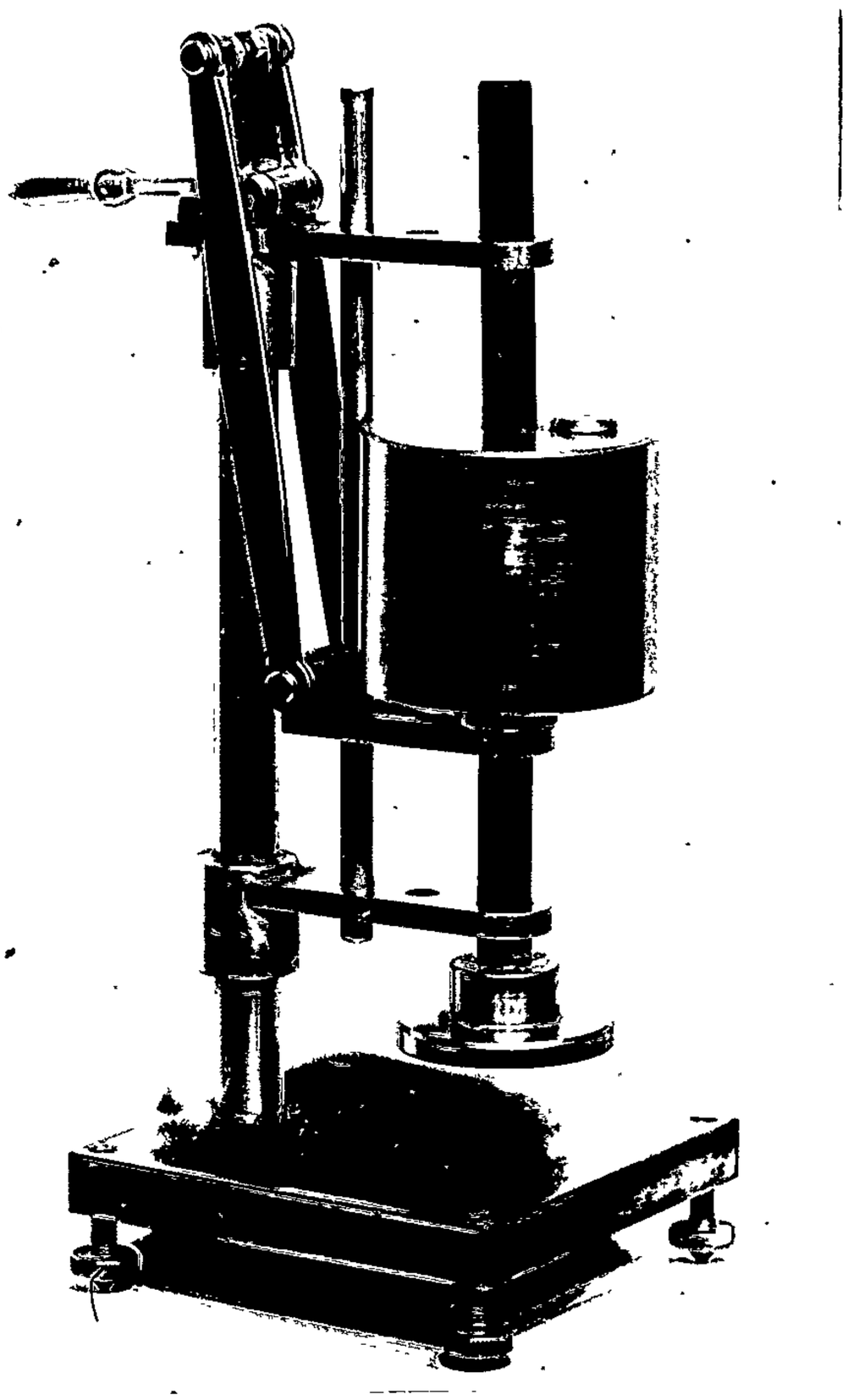


Figure 2-5

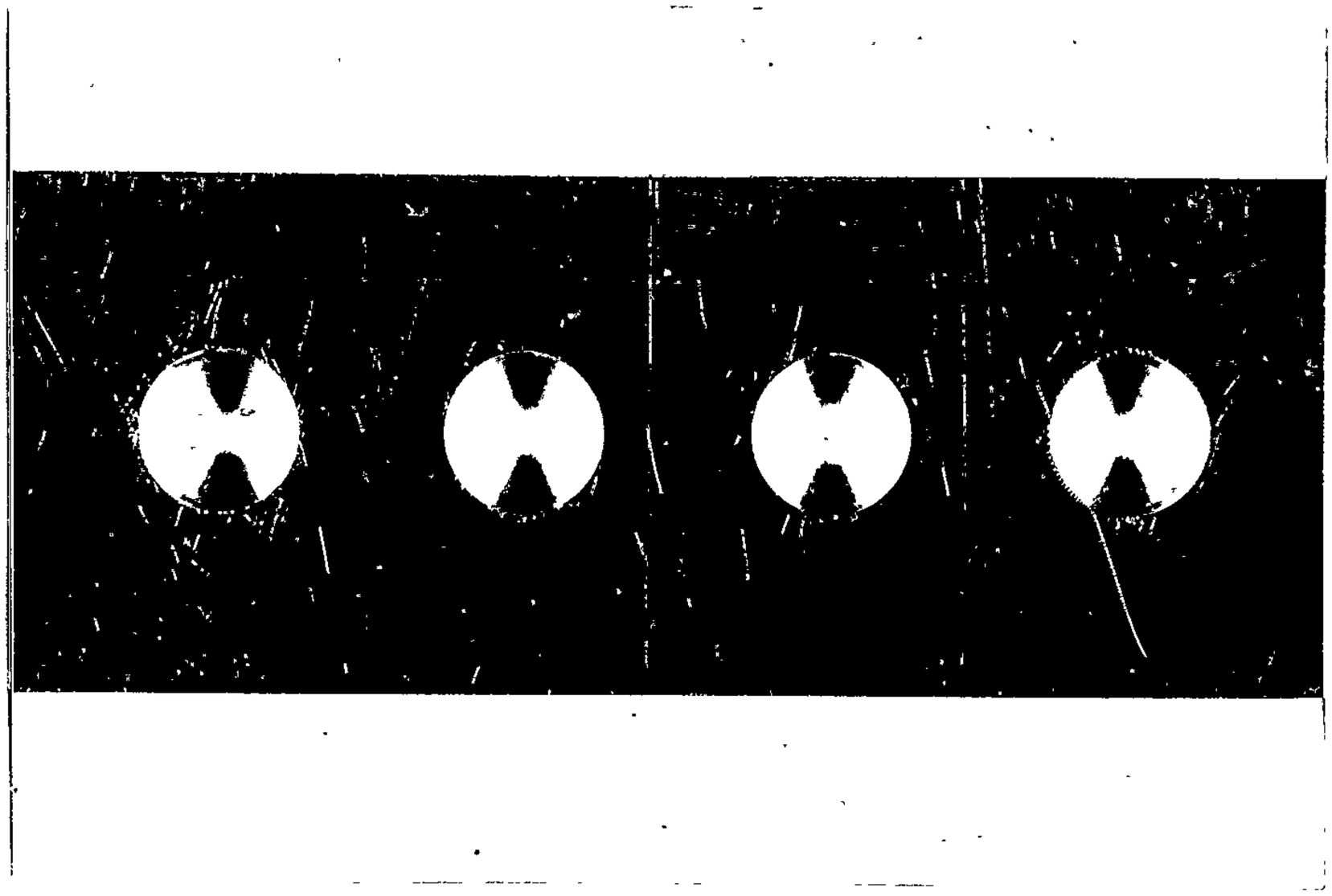


Figure 2-6

that even after the outer door had been opened for 20 seconds. the drop in temperature of the centre of the specimen was only 1°C. Tests in water were carried out in a water bath (Figure 2-8), whose temperature was maintained within ± 0.02°C.

Since prolonged heating at elevated temperatures results in a loss of plasticity of the material, a further variation in test procedure was necessary. The specifications[18-22] require that the test specimen be immersed in the water bath for 20 minutes before testing. However, heating a shellac specimen for 20 minutes at 70 and 80°C in water, would cause an increase in viscosity of the material, by leaching of the plasticiser, and this could affect the results.

A thermocouple, as described previously, was used to determine the minimum time necessary for the flow specimens to reach the required temperature. The hot junction was embedded in the centre of a flow specimen, and it was found that after two minutes at 60, 70 and 80°C, the centre of the specimen had reached ambient temperature; thus it was necessary to condition the specimen only for this time in the water bath before testing. This was confirmed by carrying out flow tests at 60°C following immersion of the material in the water bath for 2, 5, 10, 15 and 25 minutes before testing; the flow did not vary by more than 1 per cent.



Figure 2-7

Oven and Flow testing machine.

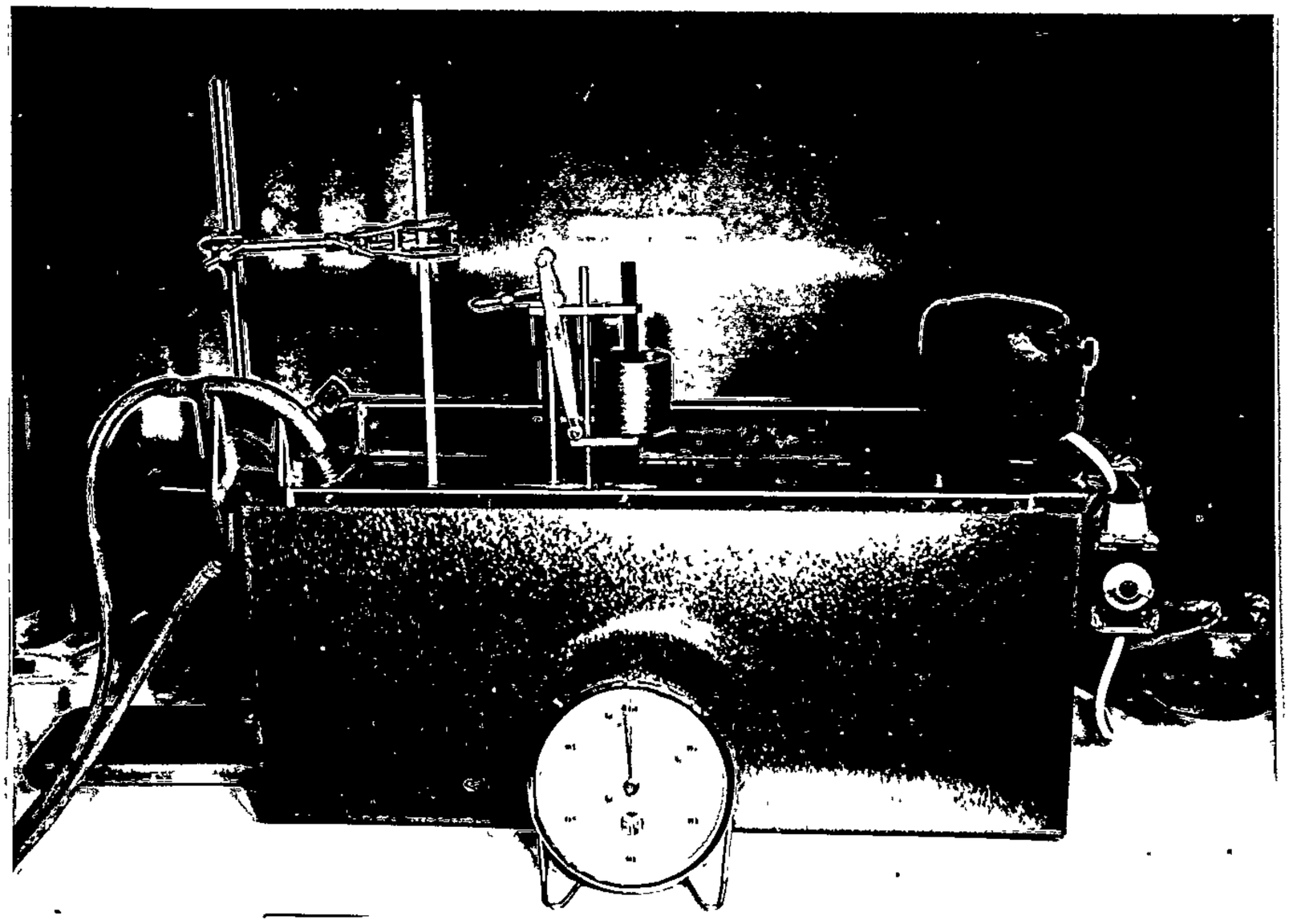


Figure 2-8

For tests in air, similar experiments showed that the specimen should be conditioned in dry heat for 10 minutes before testing.

2.2.3. Dimensional stability:

Dimensional stability after moulding is a property which is of major importance in the clinical use of these materials. Baseplates distort after moulding, due to relief of moulding stresses; these are induced into the material during manipulation, and the magnitude of the warpage depends on the thoroughness with which the material is softened before moulding. If a material is completely plastic when manipulated, subsequent stress relief and therefore warpage will be minimal. Repeated flaming of a shellac baseplate blank over a bunsen flame will render some areas more plastic than others, and overheating will reduce the plasticity of the material and make moulding difficult. Stress relief is usually manifested by a warpage away from the cast in the peripheral areas and away from the palatal area of a maxillary cast.

It was necessary to develop a means of assessing the warpage of the baseplates quantitatively.

Initially, readings of dimensional change were obtained by placing a moulded baseplate in a water bath at 37°C and using a Baty dial gauge comparator (Figure 2-9), to

measure warpage at a fixed point in the palatal area of the baseplate. Dial gauge readings were taken every minute for the first 10 minutes and then every five minutes up to one hour.

A water bath was constructed in 0.25 inch thick Perspex and water was circulated through it at 37°C from an external thermostat. The water bath was placed on the comparator table and maintained at a fixed horizontal level by three 0.25 inch stainless steel balls set in the Perspex base.

Since the dial gauge anvil had to be immersed in water at 37°C during a test, an extension rod was prepared in Invar, which has a low coefficient of thermal expansion, and attached to the spindle of the dial gauge. The dial gauge was modified so that its measuring force was reduced to 30 gm; thus only this force was exerted on the baseplate during a test.

A non-undercut maxillary stone cast was used as the die for moulding the baseplates. Absence of undercuts allowed the moulded blank to be easily removed from the cast without inducing stresses into the material on removal. The baseplate blank was softened over a bunsen flame and moulded on to the cast by finger pressure. A stainless steel disc, 0.25 inch in diameter, was embedded in the

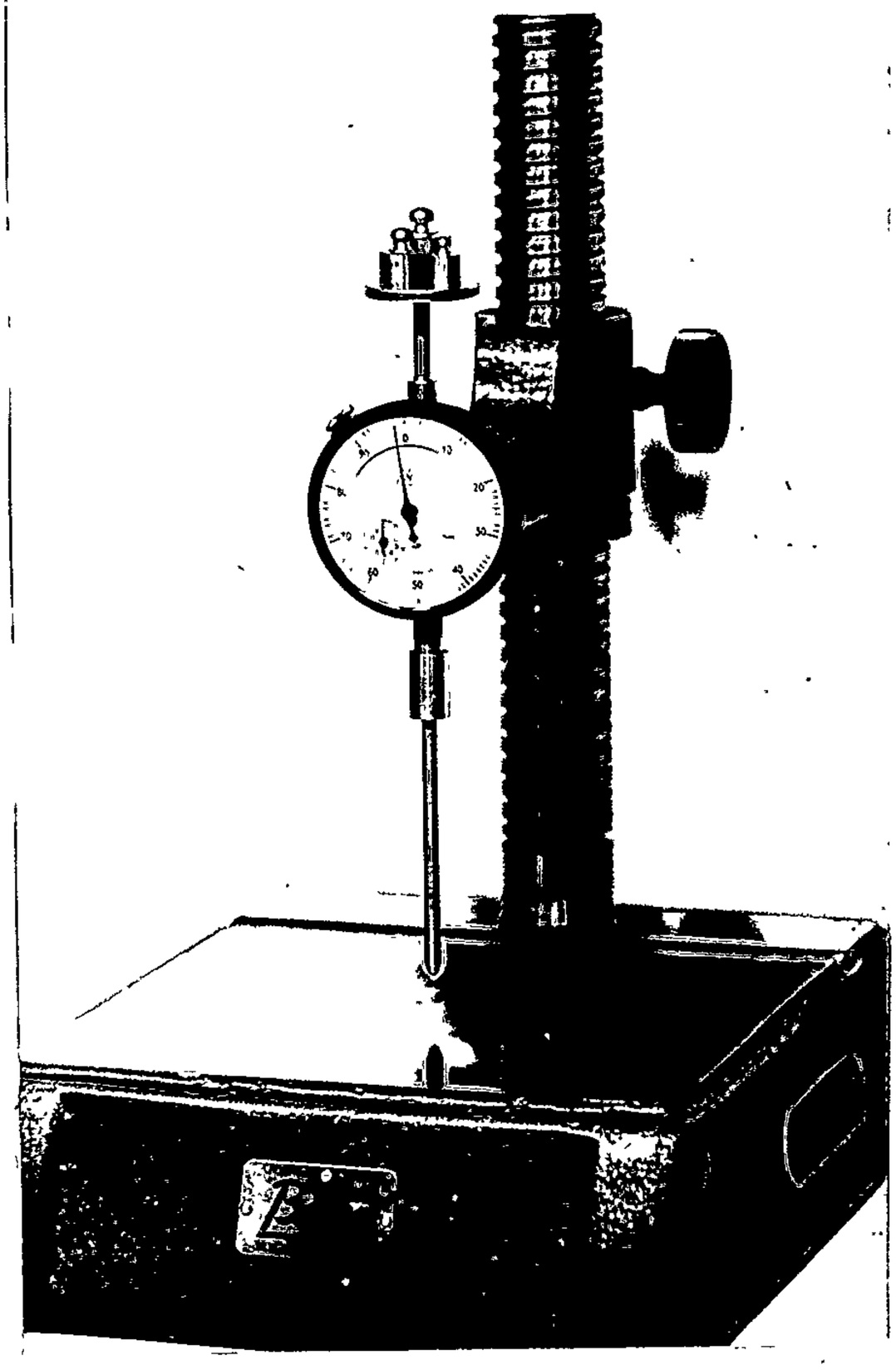


Figure 2-9

mucosal surface of the palatal section of each baseplate during moulding, to support the anvil of the dial gauge. This was necessary to prevent the anvil penetrating the baseplate during a test. Three 0.125 inch stainless steel balls were embedded in the tongue surface of the moulded baseplate, one in each tuberosity region and one in the incisive papilla region. This allowed positioning of the baseplates in a fixed horizontal plane within the water bath. The arrangement of this apparatus is shown in Figure 2-10.

Unfortunately, results obtained indicated that the continuously applied measuring force of the dial gauge on the baseplate caused flow of the material at 37°C, and dial gauge readings were thus not indicative of warpage only.

It was thought that this disadvantage could be overcome by holding the dial gauge anvil out of contact with the baseplate except when readings were taken. However, the measuring force of the dial gauge still caused flow of the material, although it was in contact for a shorter period than originally.

Use of a travelling microscope was considered, to overcome these problems of the dial gauge comparator. A piece of vitreous silica tubing, 0.13 inch in diameter by 2.0 inch long, was cemented at right angles to the centre of a stainless steel disc 0.25 inch in diameter, and a needle point was

cemented to the upper end of the tube. The stainless steel disc was embedded in the tissue surface of the palate of a moulded baseplate, and the baseplate was positioned in the water bath as before. The needle point was thus held clear of the water bath by a section of vitreous silica, whose thermal expansion is negligible over the temperature range of 20 - 37°C.

Warpage of the palate of the baseplate was now shown by vertical movement of the needle point, and this was measured by means of a vertically disposed travelling microscope reading to 0.002 mm. Readings of the vertical position of the needle point were taken at the same time intervals as before. This apparatus is illustrated in Figure 2-11.

Results of tests showed a large scatter, and even though the weight of the pointer positioned on the baseplate was of the order of one gram, flow still occurred, as indicated by the base of the pointer becoming more deeply embedded in the shellac during a test.

It can be seen that measurement of warpage should be carried out only at room temperature, to eliminate flow of the material caused by the weight of the measuring apparatus. Therefore the dial gauge comparator was used to measure the warpage of a fixed point on the palatal section

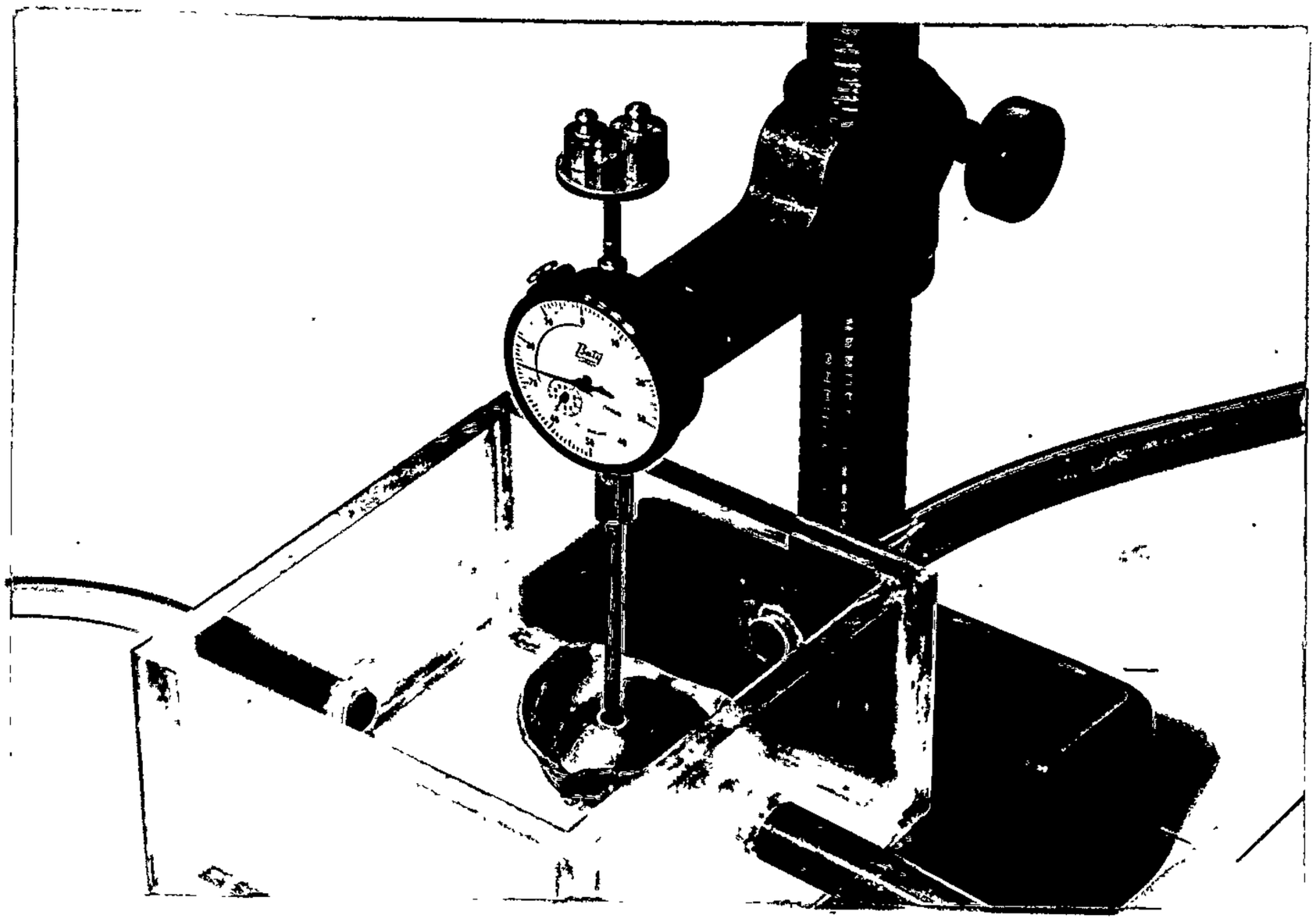


Figure 2-10

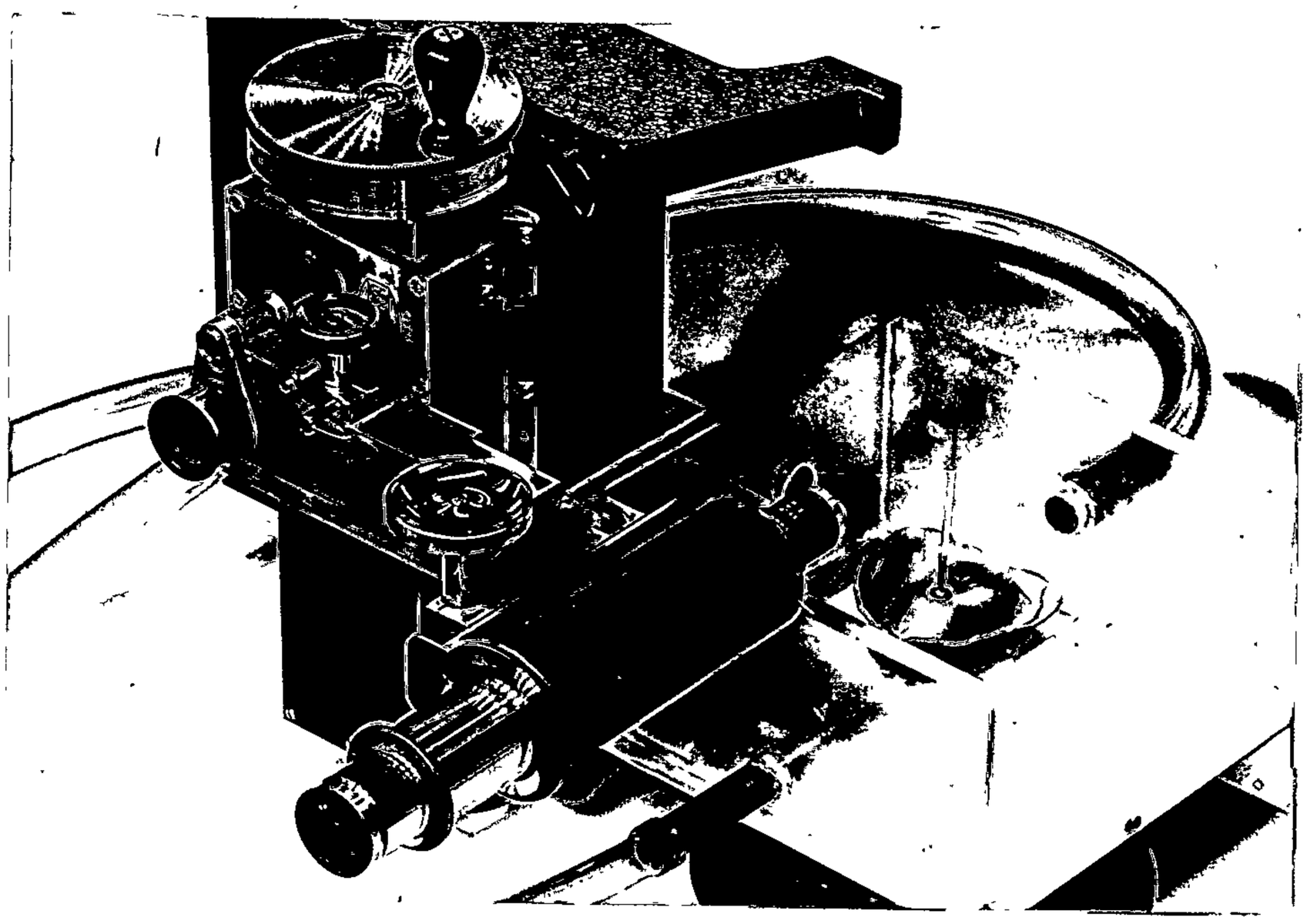


Figure 2-11

of a moulded baseplate, by taking an initial reading immediately after moulding, and again after storing the moulded baseplate in a water bath at 37°C.

Baseplates were stored in the water bath for 2, 24 and 72 hours; it was thought that stress relief may continue over these prolonged periods. In practice, baseplates would be stored in air at room temperature rather than at 37°C in water, but this latter method of storage would merely accelerate warpage which would normally occur over a longer period at 21°C in air. However, it was found that when a baseplate was stored for 24 hours in water at 37°C, it underwent flow due to its own weight (Figure 2-12). This was even greater after 72 hours' storage, and thus prevented accurate reseating of the baseplate on the cast for measurements of warpage. Measurements taken from such a baseplate would be the sum of the dimensional change from both stress relief and flow. Thus it was decided to assess warpage following storage for two hours only. Before any measurements were taken, the baseplate was cooled to room temperature, by placing it in a water bath at 21°C for five minutes. All readings were taken with the baseplate on the cast, and three stainless steel balls embedded into the base of the cast allowed relocation on the table of the comparator in the same horizontal plane. A stainless steel disc 0.25 inch in diameter, with a central indentation, was embedded in the tongue side of the palatal section of the baseplate; the pointed

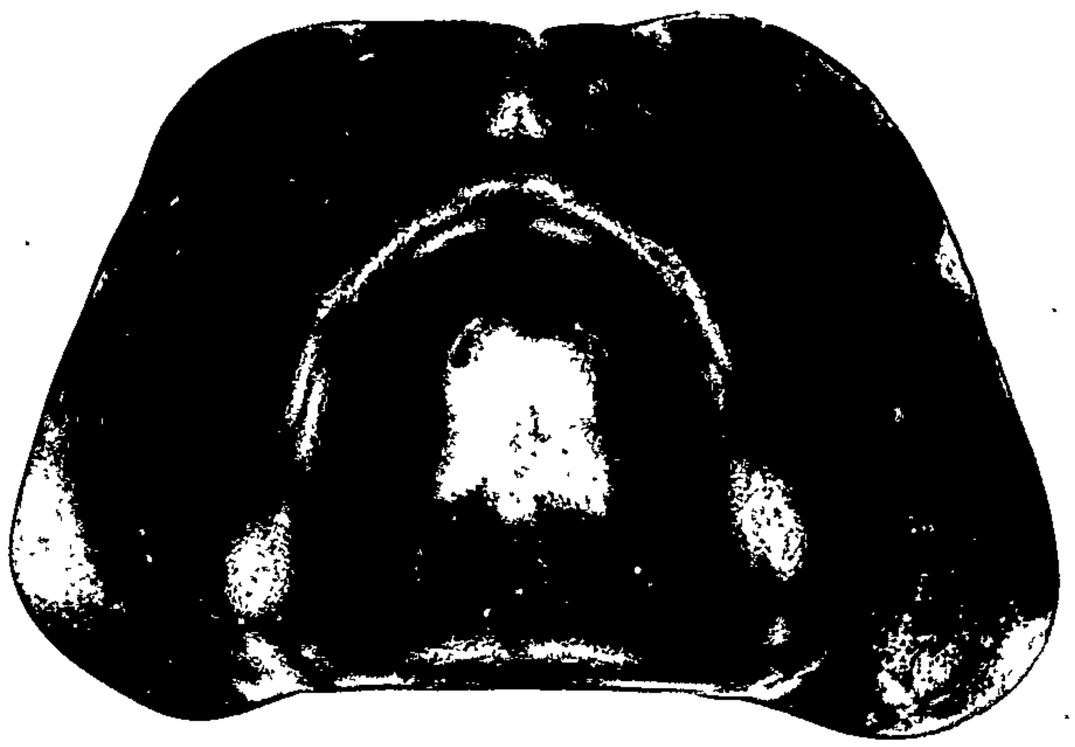


Figure 2-12

Baseplate after conditioning in water at 37°C for 24 hours; the flat areas in the maxillary tuberosity region are due to plastic deformation of the material caused by its own weight.

anvil of the dial gauge fitted into this indentation and this allowed precise repositioning of the baseplate for all measurements. Initial tests were made of the reproducibility of this method of location of the specimen. A moulded baseplate seated on the cast was positioned on the comparator table, and a series of consecutive readings was taken before warpage had occurred. After each reading, the baseplate and cast were removed from the comparator and repositioned before the next reading was taken. All readings fell within a range of $\pm$ 0.002 mm.

To eliminate the arbitrary technique of adapting the baseplate to the cast, a stone counterdie was prepared, so that moulding could be carried out in one operation, on a uniformly softened baseplate blank (Figure 2-13). It was decided to soften baseplate blanks at 60, 70, 80 and 90°C before moulding, since it was anticipated that with increasing plasticity of the material, less residual stress would be induced on moulding, and therefore warpage due to stress relief would decrease. Softening of the blanks at these temperatures was carried out both in air and in water.

2.2.4. Reproduction of surface detail:

The American and Australian specifications for dental impression compound[18,19], include a reproduction of surface detail test. In order to pass the test, the material

must reproduce the detail of a test block which has large and small grooves on its surface. The large grooves are 2 mm deep, which means that the test is only suitable for use with a fairly thick mass of softened material. Since the shellac specimens would be in the form of a thin sheet, this reproduction of surface detail test was not suitable for the shellac materials. Instead, a reproduction of surface detail test was adapted from the packing properties test for denture base resin, A.D.A. Specification No. 12[14]. It differed from the specification test in that it was used in a qualitative manner only; depth of penetration of the holes in the die was not measured, but a material was considered to show satisfactory reproduction of detail, only if it reproduced all the holes in the die. In preliminary tests, baseplate blanks were softened in air and in water at 60, 70 and 80°C and placed on the brass die (Figure 2-14) preheated to the same temperature. The baseplate blank was covered with a glass plate, 5 mm thick and 50 mm square, and a load of 10 kg applied.

One material was selected which was known to give satisfactory reproduction of detail under practical conditions, and the initial tests were carried out with this material. During these tests, the time of application of the load was increased from one to 10 minutes in steps of one minute. However, even after applying the load for 10 minutes, the

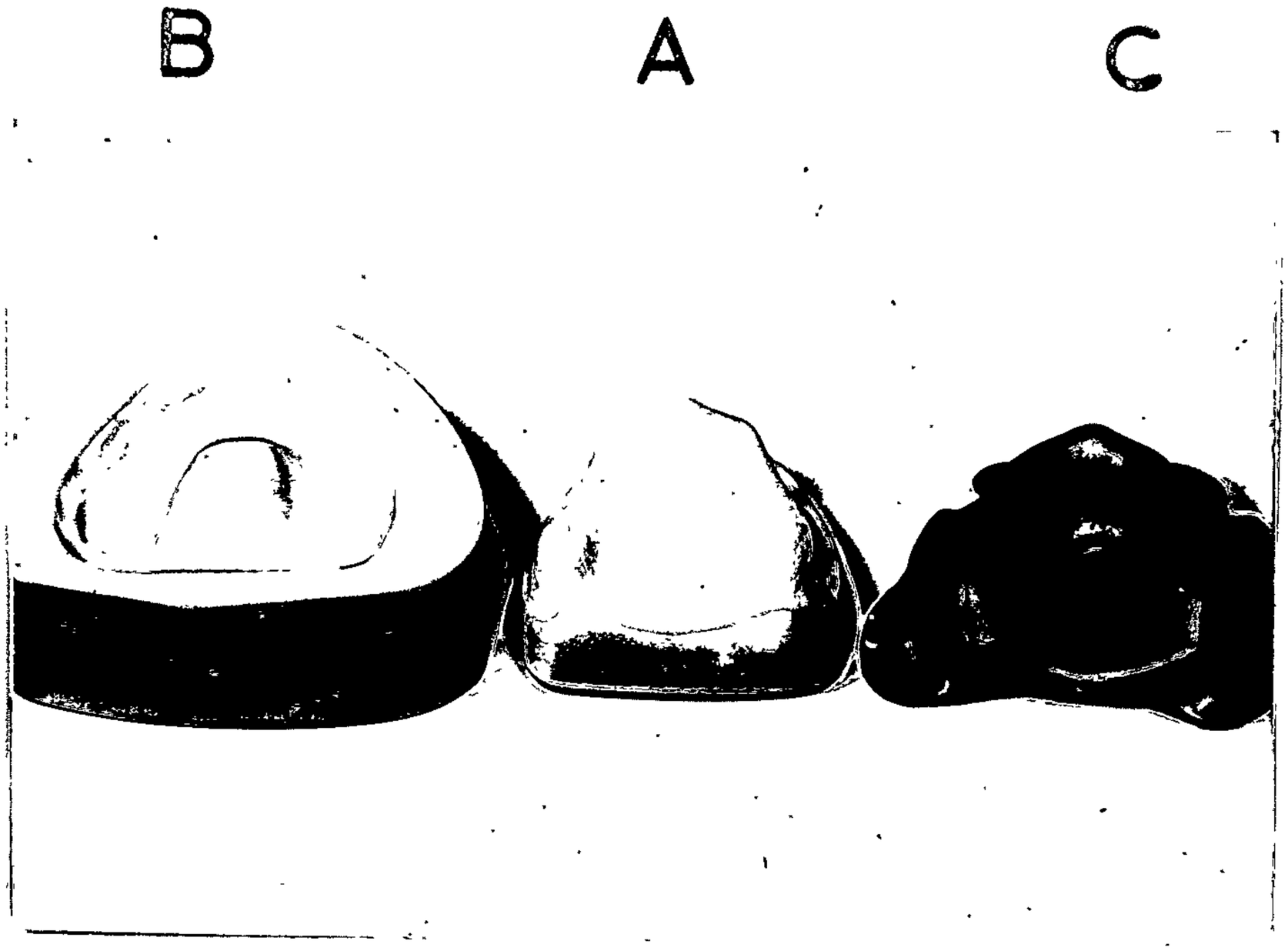


Figure 2-13

Die (A), Counter-die (B), Baseplate (C).



Figure 2-14

material did not reproduce the holes in the die. These experiments were then repeated, with a sheet of 0.25 inch polyurethane foam interposed between the softened baseplate blank and the glass plate. Under these conditions, when a load of 10 kg was applied for 10 minutes, all the holes in the die were reproduced very clearly. In order for the test to be as selective as possible, it was necessary to reduce the applied load and its time of application until the holes in the die were just reproduced. It was found that a load of 0.5 kg when applied for one minute allowed this particular material to reproduce all the holes in the die; it was under these conditions that all subsequent tests, on all shellac materials, were carried out.

It was found, again using an embedded thermocouple, that a baseplate blank had reached ambient temperature after two minutes' immersion in water at 60, 70 and 80°C, and after five minutes in air at these temperatures. Therefore the baseplate blanks were heated for these periods prior to testing.

2.3. APPARATUS.

2.3.1. Transverse strength and rigidity:

The apparatus used for testing strength and rigidity is illustrated in its final form in Figure 2-15(a-f). The

specimen (A) was supported as a simple beam and subjected to three point loading; the specimen supports and loading plunger followed the usual design for transverse tests on acrylic resin[12,13,14]. The supports (B) were two rollers 3.2 mm in diameter, 50 mm apart, rotating in bushes of Polytetrafluorethylene (P.T.F.E.). Loads were applied in the centre of the span through a vertical plunger (C), supported by six ball races (D). The plunger was loaded by means of a lever (E), coupled to its upper end, and the lever was pivoted at a fulcrum (F), where it rotated on ball-races.

The lever arm and plunger could be counterbalanced by an adjustable weight (G), so that tests could begin at an initial load of zero. During a test, a continuously increasing load was applied to the specimen by the movement of two 5 kg lead weights (H) along the lever arm. The weights were free to rotate about the transverse shaft on which they were mounted.

The weights were supported one on each side of a carriage (I), which moved along the top of the lever arm on ball-races, and was driven by a miniature electric motor (J), powered by a battery charger. The shaft speed of the motor was reduced by means of a series of reduction gears housed in a gear box in the front of the carriage; the final drive was by means of a pinion acting on a rack fixed to the top of the

beam. This gearing resulted in a marked increase in torque of the system and allowed maintenance of the required rate of loading. Ball-races mounted within the carriage bore against the sides of the rack and gave lateral stability to the movable unit.

The loading rate, as suggested by the U.S. Government's Federal Specification for baseplates[15], was obtained by arbitrarily altering the magnitude of the movable load and the position of attachment of the plunger to the lever arm. Movement of the carriage along the lever resulted in a continuously increasing load of 1500 gm/minute. As well as loading at a constant rate, the apparatus could be used to load acrylic resin specimens according to the incremental programme defined in standard specifications for these materials[12,13,14]. A pointer on the carriage moved along a scale on the lever arm, to show the load applied at any given time.

A control panel (K), included a reversing switch and a bypass mechanism. The latter was necessary, since a safety device in the form of a circuit breaker arrested the motor when the carriage was reversed beyond the fulcrum point. The bypass completed the circuit, allowing forward movement of the carriage until the starting point was reached, at which stage the original circuit was intact and the bypass

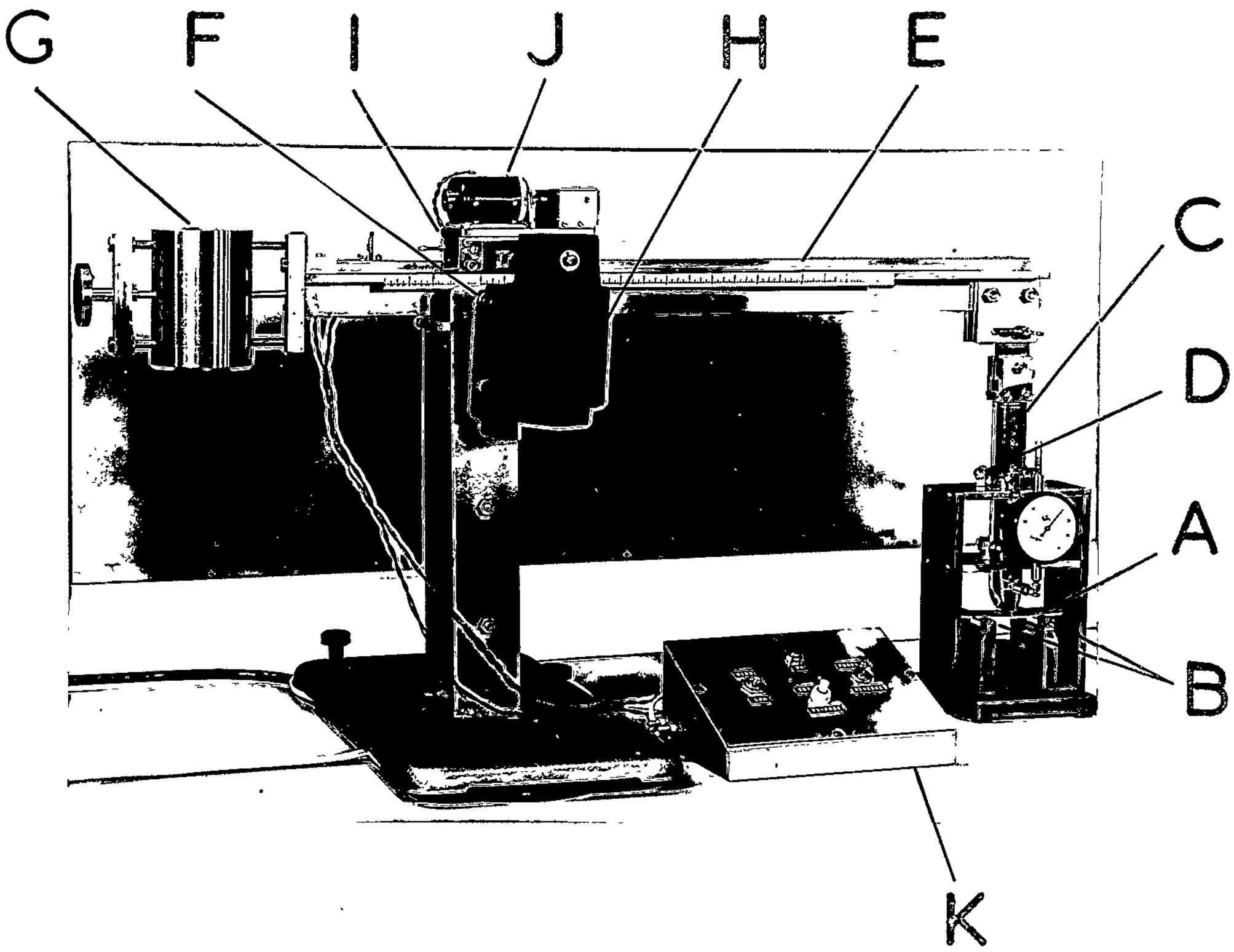


Figure 2-15(a)

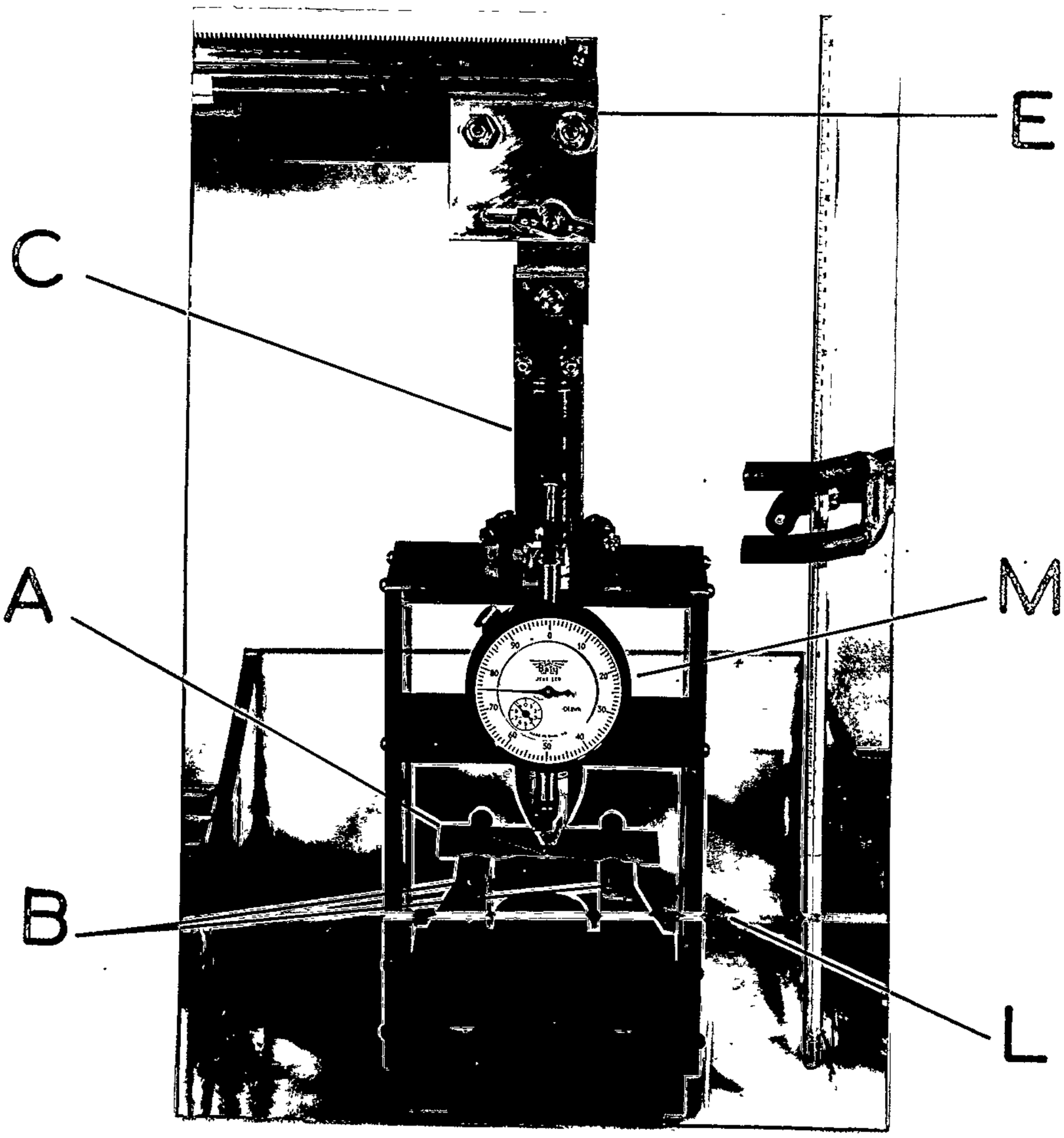


Figure 2-15(b)

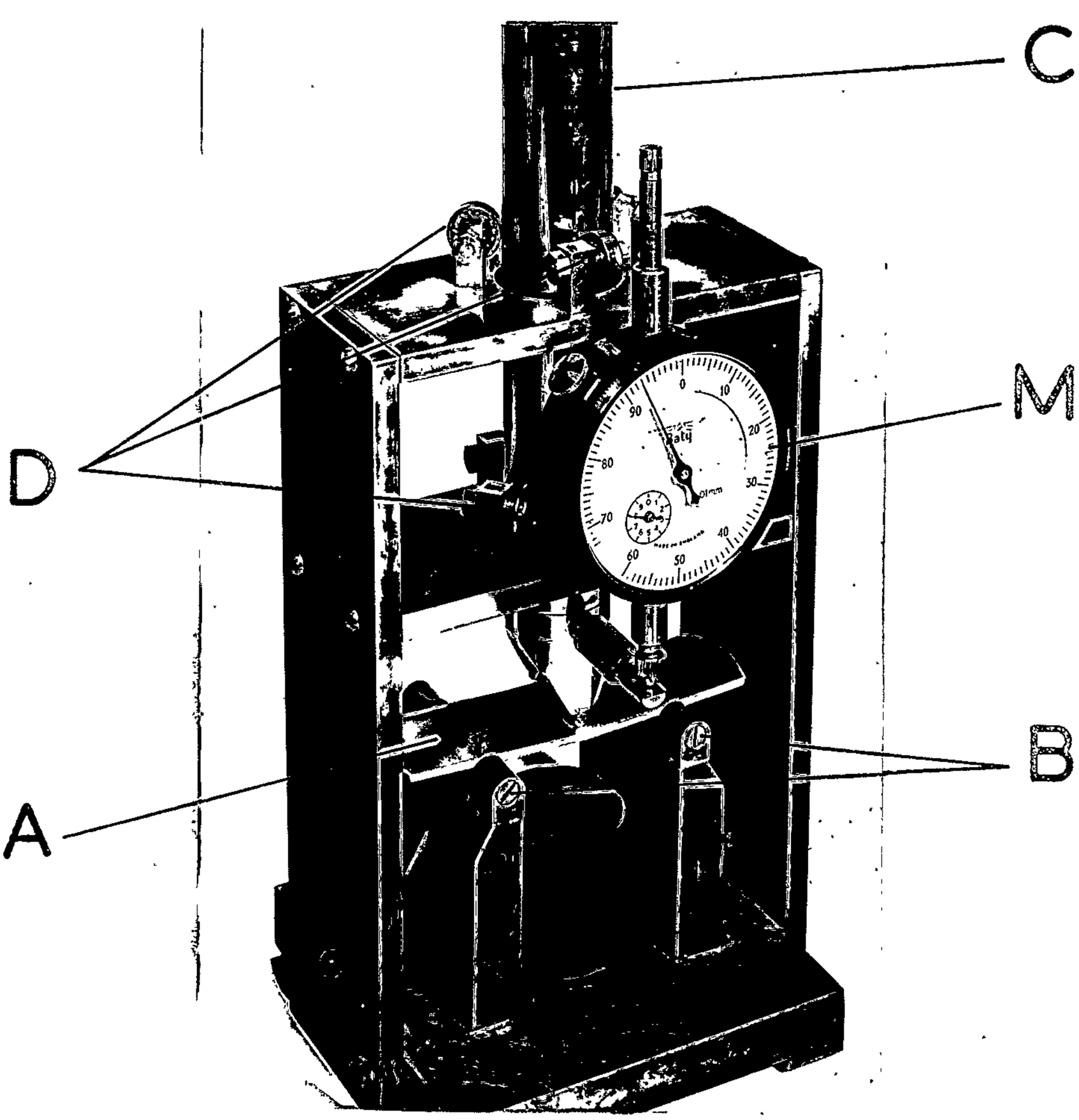


Figure 2-15(c)

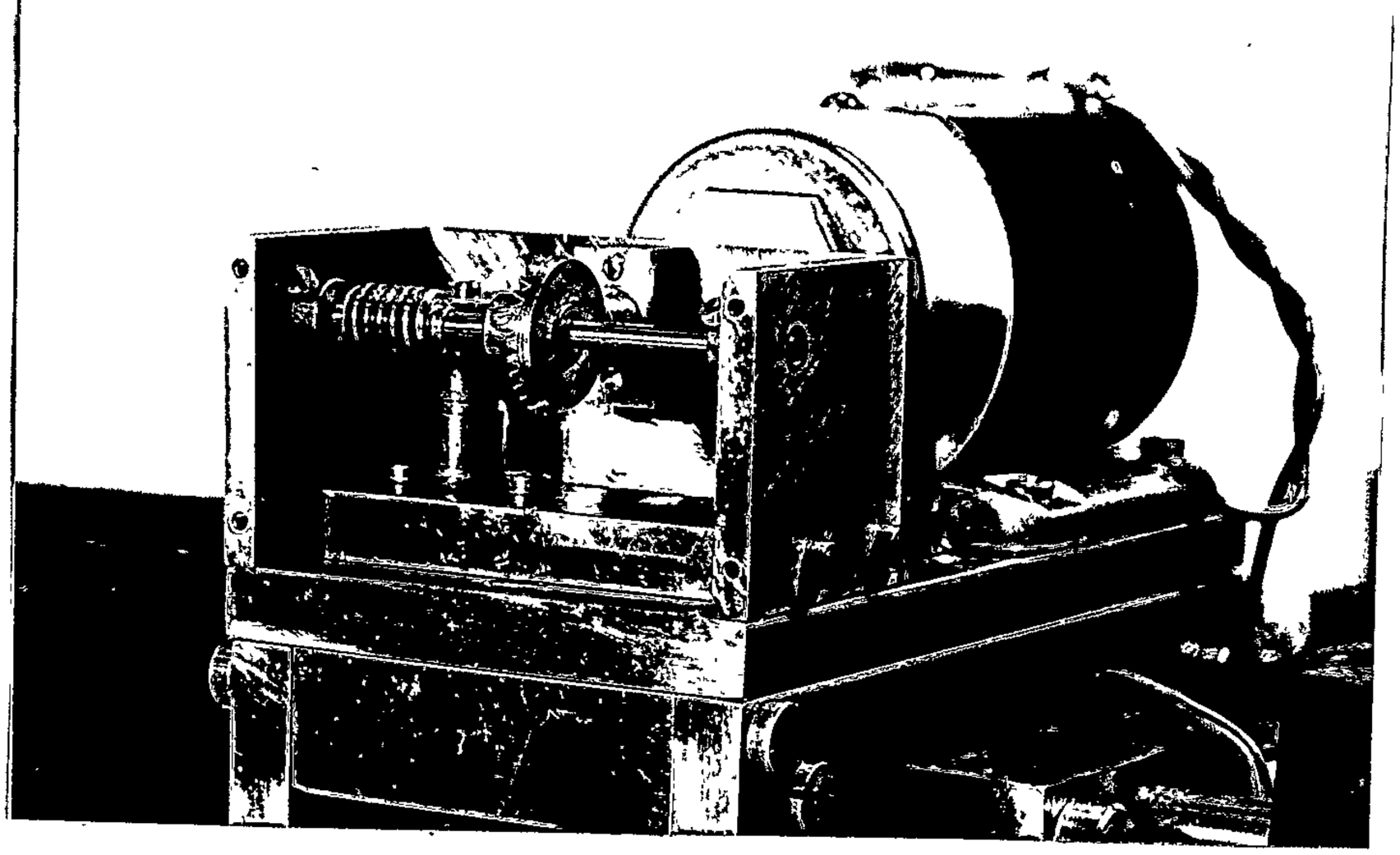


Figure 2-15(d)

The gear box (front view).

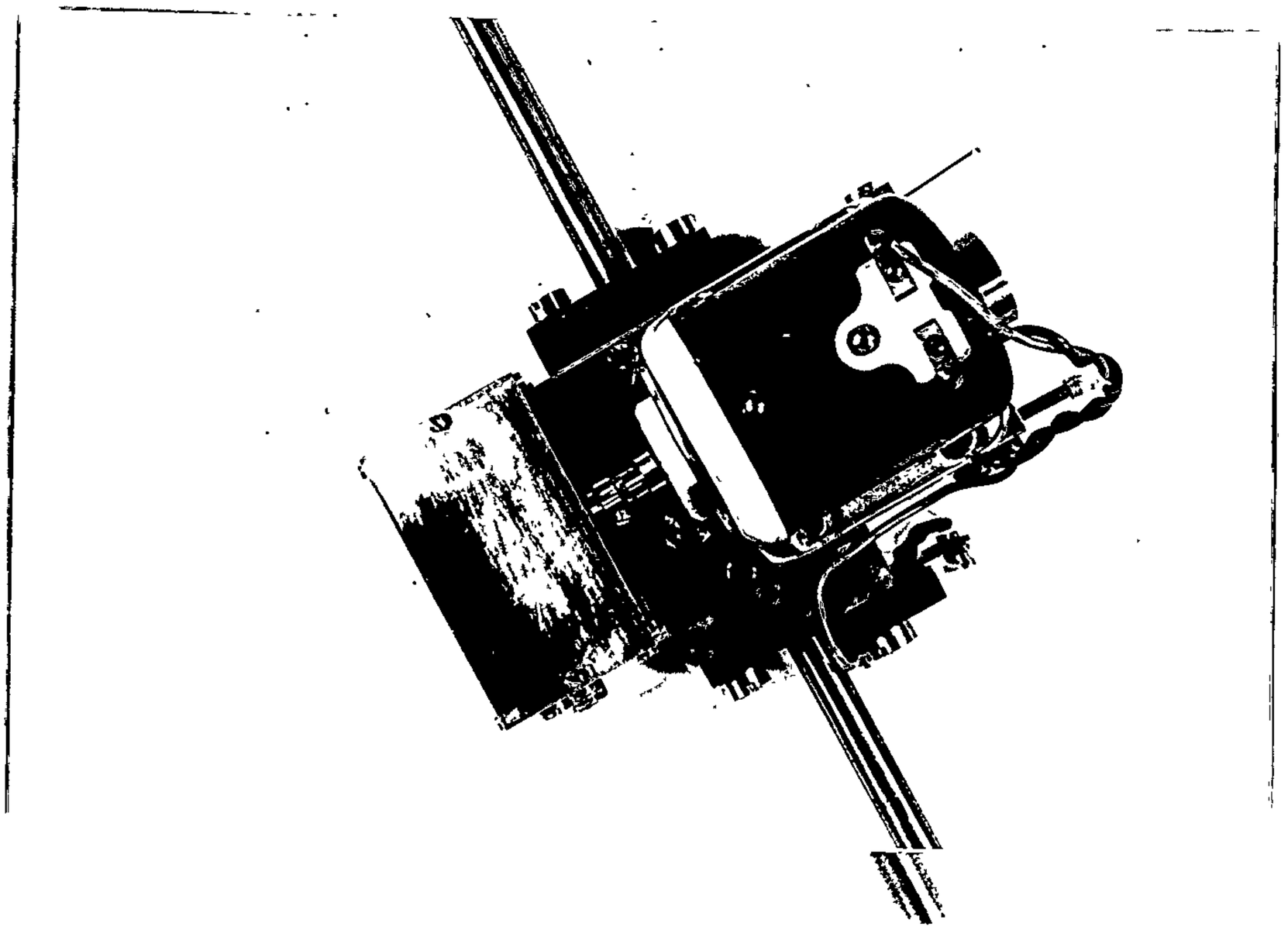


Figure 2-15(e)

Carriage, motor and gear box (from above).

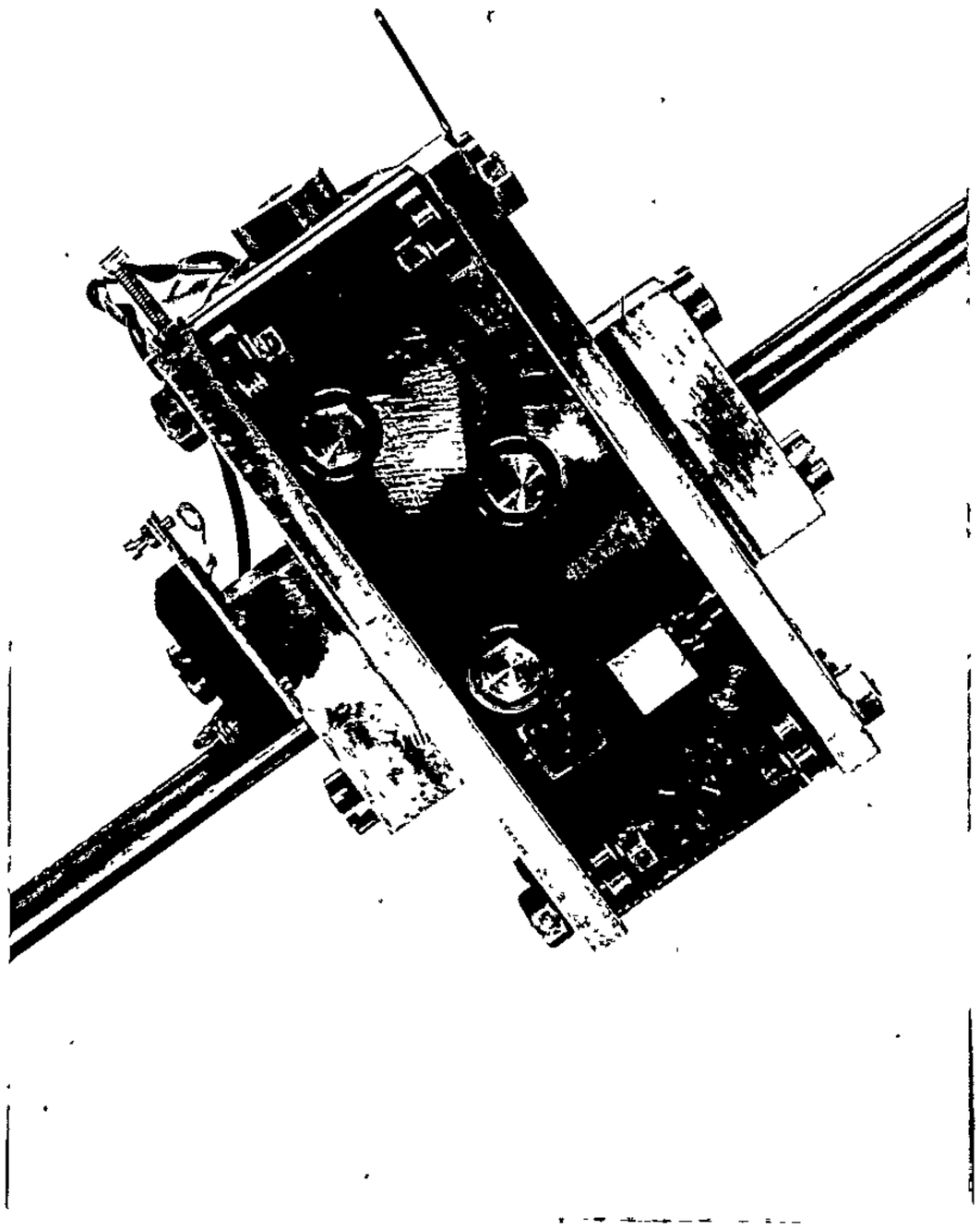


Figure 2-15(f)

Carriage (from below) to show lateral stabilizing ball races, which bear against the rack.

mechanism could be switched off. Movement of the carriage was controlled by a foot switch.

When tests were made under water, the specimen supports and lower part of the plunger were immersed in a small water bath (L), through which water at the required temperature was circulated from an external thermostat.

In all tests, the specimen deflection resulting from any load could be read from the dial gauge (M), which recorded vertical movement of the plunger. Because the load was applied mechanically, taking the dial gauge readings was more convenient than with the testing machine specified for transverse tests on denture base resins[12,13,14].

2.3.2. Flow:

The flow testing machine is illustrated in Figure 2-5. It consisted of a weight (A), an ebonite shaft (B) and a brass platen (C). The total weight in air of these three components was 2000 gm. The non-conducting ebonite shaft minimised heat loss from the specimen by conduction. The brass platen was 51 mm in diameter and 6.5 mm thick. When tests were carried out in water, the bottom of the specimen was positioned 51 mm below the surface of the water in the water bath.

The mould used for specimen preparation (Figure 2-6) was a flat stainless steel plate 6.0 mm thick containing four

holes 10.0 mm in diameter.

Tests in air were carried out in an oven (Figure 2-7) which maintained temperature within $\pm$ 1°C, whilst tests under water were carried out in a water bath whose temperature was thermostatically controlled to $\pm$ 0.02°C (Figure 2-8).

2.3.3. Dimensional stability:

The apparatus is illustrated in Figure 2-13. A non-undercut maxillary stone cast (A) was used as the die upon which baseplate blanks were moulded. Moulding of specimens was carried out on this die by means of a stone counterdie (B). During moulding of a specimen, a small stainless steel disc 3 mm in diameter and 0.5 mm thick (C) was embedded in the centre of the palatal surface of the specimen, on the tongue side. This had a small central indentation which acted as a reference point for measurement of palatal warpage.

Warpage was assessed by placing the baseplate, on the cast, on the table of a dial gauge comparator (Figure 2-16). The cast had three stainless steel ball bearings embedded in its base, to ensure its reproducible orientation in the horizontal plane. The pointed anvil of the dial gauge, which fitted into the depression in the stainless steel disc (C, Figure 2-13) completed the correct location of the specimen, relative to the dial gauge.

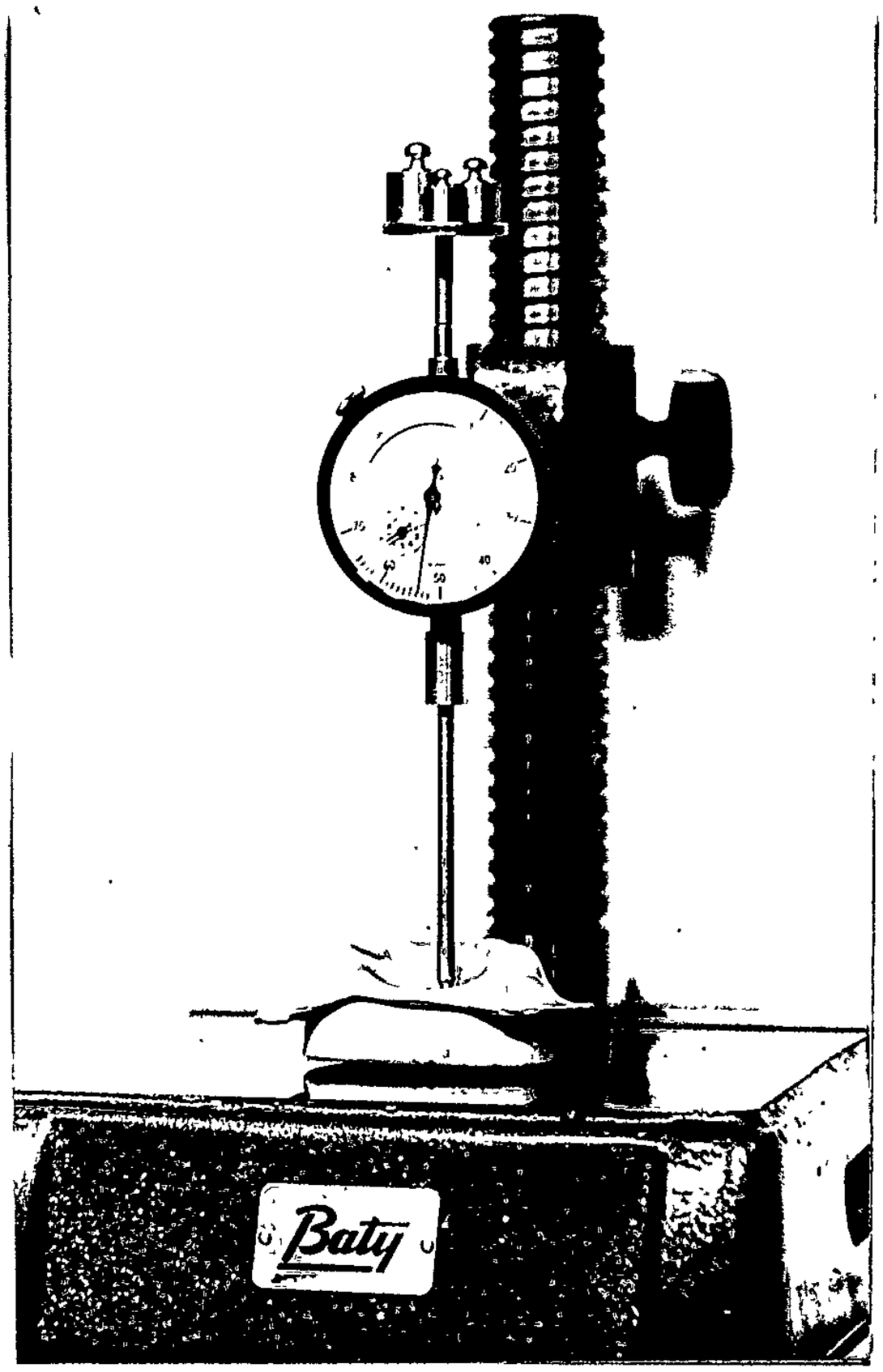


Figure 2-16

Dial gauge readings taken before and after stress relief gave an indication of the amount of warpage of the baseplate, by measuring the vertical movement in the centre of the palate, and thus the resulting palatal discrepancy.

2.3.4. Reproduction of surface detail:

The brass die used for the reproduction of surface detail test is seen in Figure 2-14. The brass plate was 5 cm square and 1 cm thick. Holes 0.75 mm in diameter were drilled through the plate, 0.5 cm apart, along the sides of a 2 cm square in the centre of the brass plate. During a test, a 5 cm square sheet of polyurethane foam, 0.5 cm thick, was interposed between the specimen and a 0.5 kg weight.

2.4. EXPERIMENTAL METHOD.

2.4.1. Transverse strength and rigidity:

Specimens were prepared from the widest section of a baseplate blank; they were 2.5 cm wide and at least 6.0 cm long, as suggested by the U.S. Federal Specification[15]. A metal rule 2.5 cm wide was used as a guide, and the baseplate blank was scored with a sharp scalpel along the edges of the rule, and the excess broken off. Width of the specimen was checked with vernier calipers and any necessary adjustments were made with 220A silicon carbide abrasive paper. Five

measurements of thickness were taken across the centre of the test specimen with a micrometer screw gauge, and a mean determined.

The specimen was positioned across the span of the testing machine and the test commenced. Readings of specimen deflection were taken from the dial gauge every five seconds until the specimen fractured, at which time the machine was immediately stopped and the fracture load read from the scale on the beam. Since the load increased at the rate of 1500 gm/minute and readings of deflection were taken every five seconds, it was possible to draw load-deflection curves for each test.

When tests were carried out at 37°C, a water bath was positioned around the specimen supports, and water at the desired temperature circulated through the bath from an external thermostat.

2.4.2. Flow:

Small pieces of baseplate material were placed in a 50 ml iron crucible and heated in an oven at a temperature of 90 ± 1°C. After a period of 7 to 12 minutes, depending on the material, it was sufficiently plastic to be introduced with a spatula into the mould used for specimen preparation. The mould was preheated to 90 ± 1°C and placed on a smooth

flat glass plate (6 in. long, 3 in. wide and 0.8 in. thick) covered with tin foil, also preheated to this temperature. The mould was slightly overfilled with material, and covered with another tin foiled glass plate of similar dimensions, also preheated to 90 $\pm$ 1°C. A load of 9 kg was applied to the top glass plate for 10 minutes. The mould was then placed in water at 21 $\pm$ 1°C for 10 minutes, after which time the tin foiled glass plates were separated and gross excess material removed with a scalpel. The specimens were removed from the mould, and any minor irregularities in the contour of the flat surface of the specimens were removed with 220A silicon carbide abrasive paper. All specimens were stored for at least 24 hours at 21 $\pm$ 1°C before testing.

The original length of the specimen was determined using a micrometer screw gauge; four measurements were made around the circumference and one measurement on the centre of the specimen. The measurements were made to the nearest 0.002 mm.

Flow tests were made in air at 21, 60, 70 and 80°C, and in water at 37, 60, 70 and 80°C. Tests in air at 21°C were made in a laboratory whose temperature was controlled to $\pm$ 1°C. Tests in air at elevated temperatures were made in an oven, thermostatically controlled to $\pm$ 1°C. All tests in water were made in a water bath, thermostatically controlled to $\pm$ 0.02°C.

At all temperatures above room temperature, the flow testing apparatus was conditioned for 20 minutes before a test was made. Specimens were conditioned for two minutes in the water bath before tests in water, or for 10 minutes in the oven, before tests in air. To make a flow test, a sheet of 0.001 in. tin foil was placed between the instrument and each end of the specimen, and a constant axial load of 2000 gm was then applied for 10 minutes. After this time, the specimen was removed and cooled in air for 20 minutes. The foil was stripped off and the final length was determined. The flow, as indicated by the change in length, was expressed as a percentage of the original length. At least two tests were carried out under each set of conditions.

2.4.3. Dimensional stability:

A baseplate blank was softened at the appropriate temperature, and immediately placed on the cast and moulded on to the palatal section with finger pressure. A stainless steel disc with a central indentation was placed on the softened shellac in the centre of the palatal area, and the counterdie positioned. A weight of 10 kg, placed on the counterdie for one minute, moulded the softened blank to the contours of the cast. The weight and counterdie were then removed and the baseplate and cast were immersed in water at 21 $\pm$ 1°C for five minutes. After this time the baseplate,

seated on the cast, was positioned on the table of the dial gauge comparator, and an initial reading of the dial gauge taken. The baseplate was then removed from the cast, immersed in a water bath at 37°C for two hours, and again cooled to room temperature by immersion in water at 21 ± 1°C for five minutes. It was then reseated on the cast and relocated on the table of the dial gauge comparator; a second reading from the dial gauge was taken and the difference between the two readings was a measure of the warpage in the centre of the palate of the baseplate.

Tests were carried out on baseplates which had been moulded after softening for two minutes at 60, 70, 80 and 90°C in water, and after softening for 10 minutes at 60, 70, 80 and 90°C in air.

2.4.4. Reproduction of surface detail:

Baseplate blanks were softened for two minutes in a water bath at temperatures of 60, 70 and 80°C, or for 10 minutes in an oven at 60, 70 and 80°C. Each softened blank was placed on the die used to assess reproduction of surface detail (Section 2.3.4) , which had been preheated to the same temperature as the softened baseplate blank. A sheet of 0.25 inch polyurethane foam, 5 cm square, was placed over the baseplate blank, and a glass plate, 5 mm thick and 5 cm square,

loaded to 0.5kg, was positioned over the foam for one minute. After this time the baseplate blank was removed from the die and examined; if all the holes in the die were reproduced by the baseplate, then the material was considered to give satisfactory reproduction of detail under the particular softening conditions used.

2.5. RESULTS.

2.5.1. Transverse strength and rigidity:

The results obtained from the strength and rigidity tests are presented in Table 2-1. Each value given is the mean of results from at least five tests. The specimen thicknesses apply to all specimens of a given material.

Load-deflection graphs of each test are shown in Figures 2-17 to 2-27. Because some of the tests were made in an earlier version of the testing machine, which applied a load of 500gm at the beginning of the test (page 16), all results have been plotted in this way. The results of tests made in the final version of the machine, which started at a zero load, have been corrected accordingly.

2.5.2. Flow:

The results of flow tests are listed in Table 2-2. At least two tests for flow were carried out under each set of conditions and the mean value is recorded in the Table, expressed as a percentage. These tests gave very reproducible results, and in no case was the total scatter of a set of results more than $\pm$ 1 per cent.

TABLE 2-1.

TRANSVERSE STRENGTH & RIGIDITY

Material Tested	No. of Tests	Temp. of Test (°C)	Thickness of Specimens (mm)	Average Deflection (mm) at 1500 gm	at 2000 gm	at 2500 gm	Total	Fracture Load (kg)
Impo Brown	5	21	1.5	1.2	1.9	-	2.3	2.3
	5	37		1.7	-	-	2.4	1.6
Impo Pink	5	21	1.5	1.4	2.2	-	2.2	1.8
	5	37		2.7	-	-	2.6	1.4
Ainsworth Plastic Aluminium	5	21	1.9	1.3	1.0	1.4	1.3	2.5
	5	37		1.8	1.9	-	2.1	2.1
Ainsworth Brown (Injection moulded)	5	21	1.5	1.8	-	-	2.7	2.0
	5	37		6.0	-	-	10.5	1.8
Ainsworth Pink (Injection moulded)	5	21	1.4	1.7	2.5	-	2.9	2.3
	5	37		1.9	3.1	-	4.1	1.7
Ainsworth Aluminium (Injection moulded)	5	21	2.0	0.8	1.1	1.3	1.4	3.1
	5	37		0.8	1.2	1.9	2.0	2.2
Alston Maroon	5	21	1.4	0.9	1.6	-	1.5	2.0
	5	37		1.4	-	-	2.1	1.7

TABLE 2-1. (Contd.)

Material Tested	No. of Tests	Temp. of Test (°C)	Thickness of Specimens (mm)	Average Deflection (mm) at 1500 gm	at 2000 gm	at 2500 gm	Total	Fracture Load (kg)
Ash Pink	5	21	1.4	0.7	1.2	1.5	1.7	2.6
	5	37		0.8	1.4	-	1.5	2.0
Ash Metallized	5	21	1.9	0.4	0.6	1.0	1.4	3.3
	5	37		0.5	1.0	1.3	1.3	2.5
Yellow-trays	5	21	1.8	0.4	0.6	0.8	1.2	3.1
	5	37		0.6	1.2	-	1.2	2.0
Cavex	5	21	1.4	0.7	1.1	-	1.2	2.2
	5	37		1.0	-	-	1.2	1.7

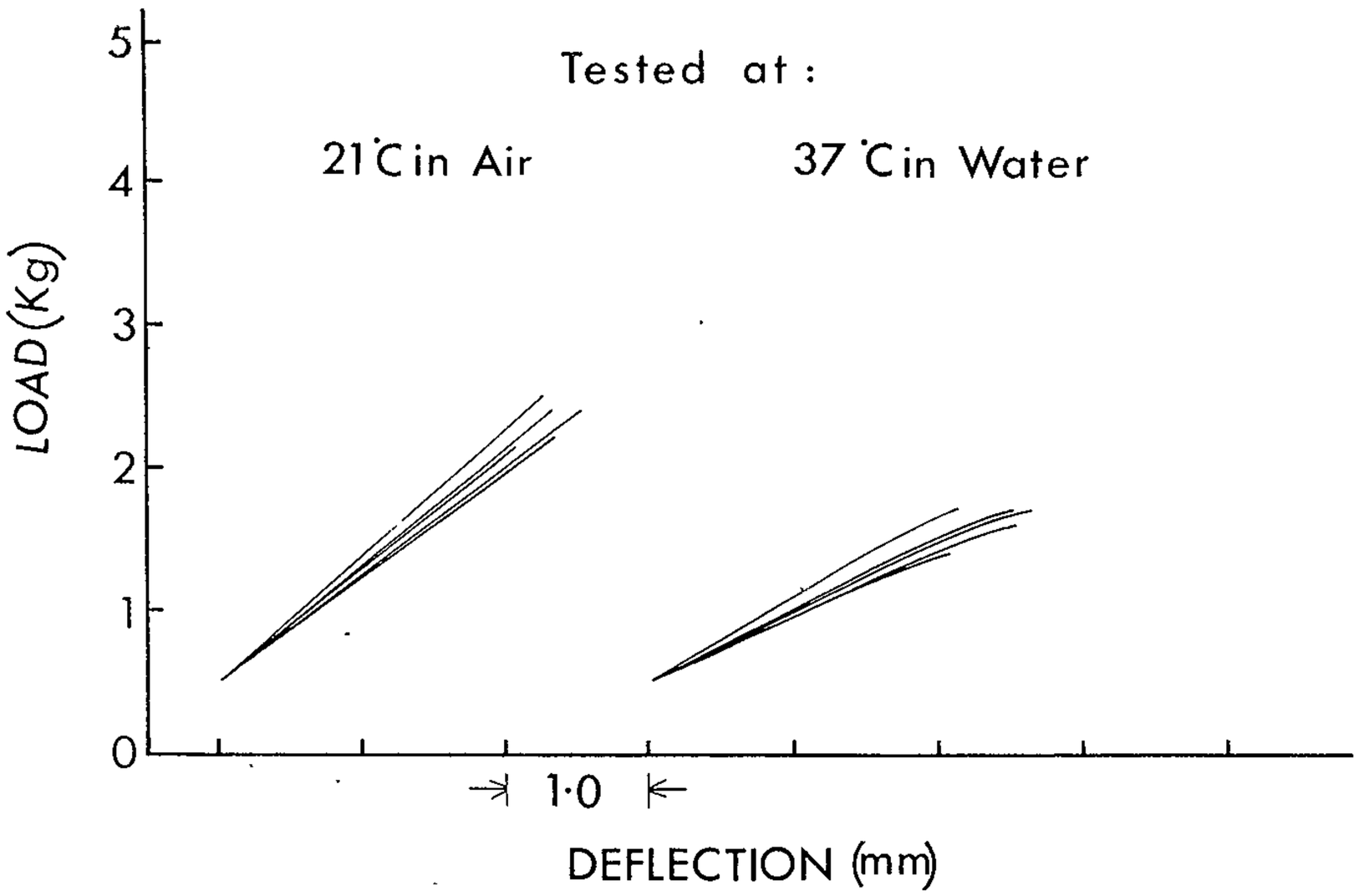


Figure 2-17

Load-deflection graph for Impo Brown.

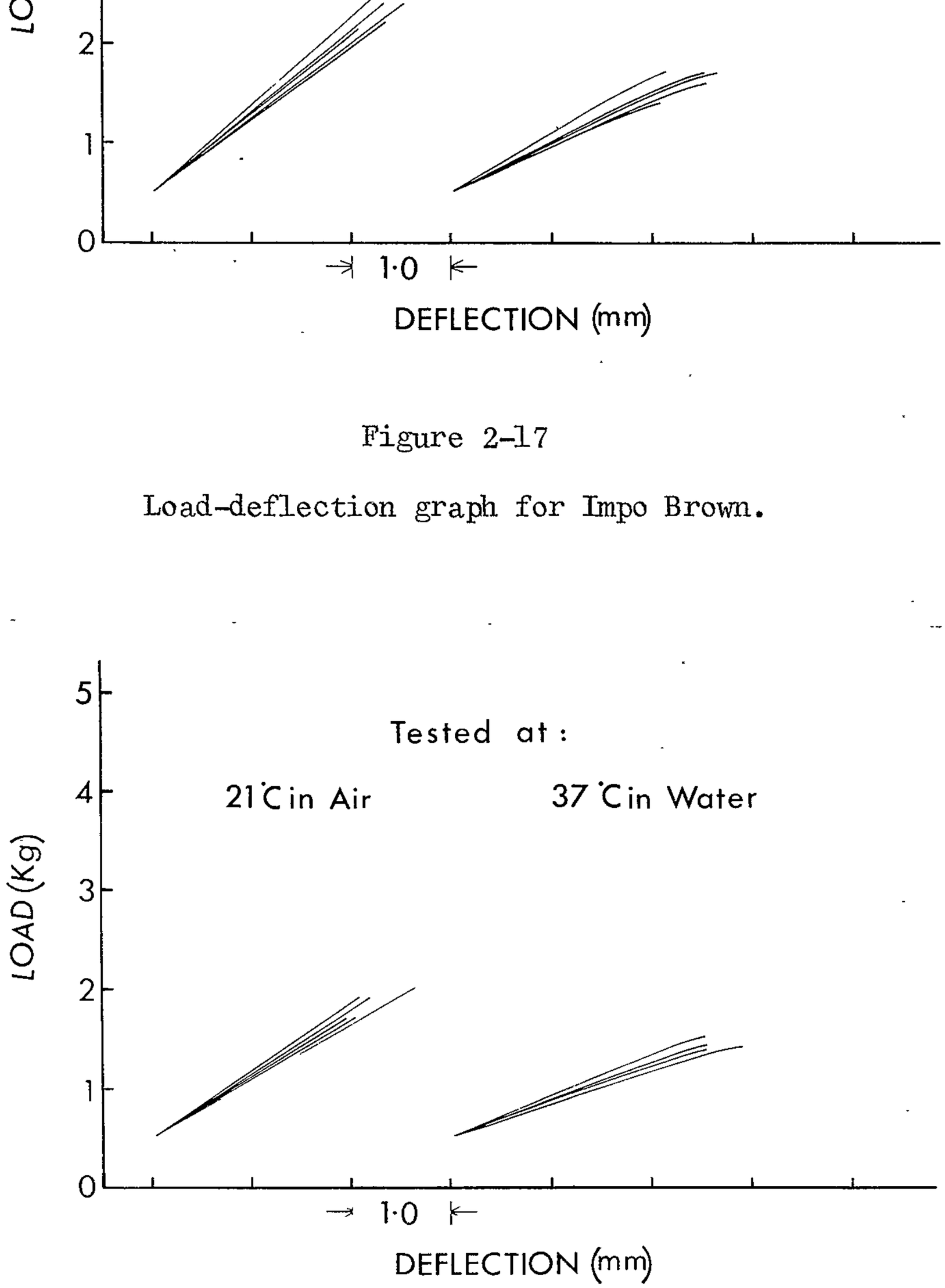


Figure 2-18

Load-deflection graph for Impo Pink.

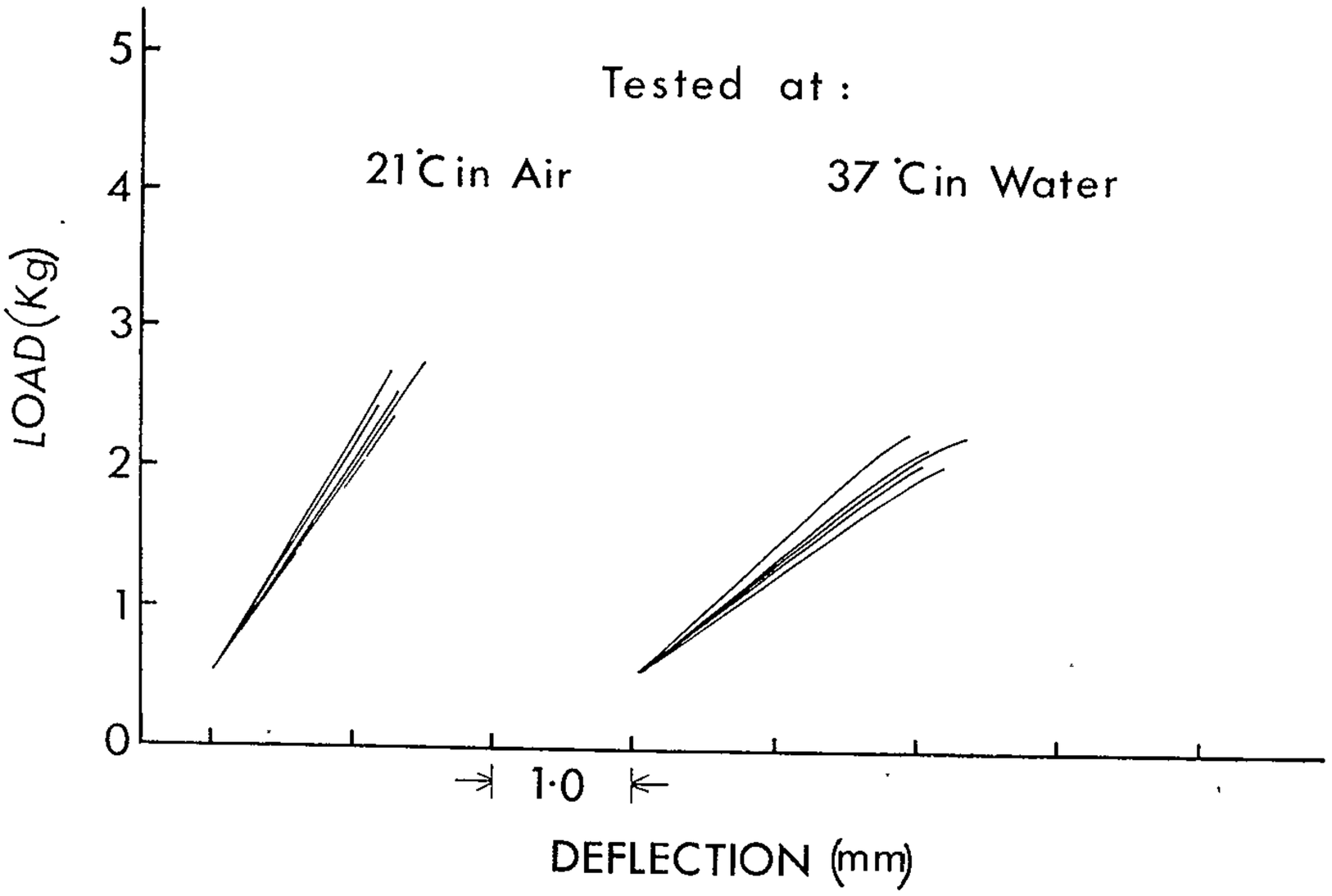


Figure 2-19

Load-deflection graph for Ainsworth Plastic Aluminium.

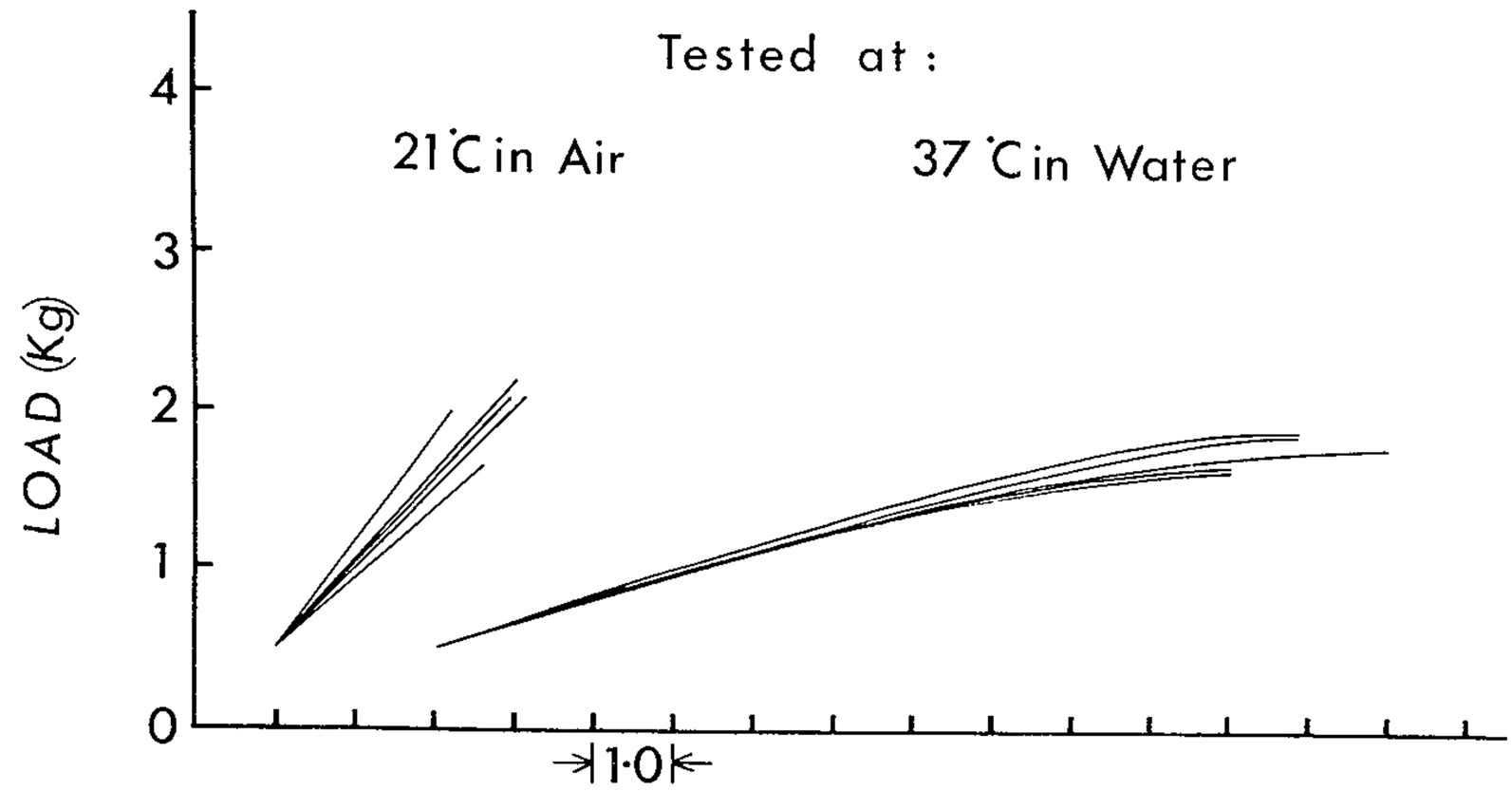


Figure 2-20

Load-deflection graph for Ainsworth Brown.

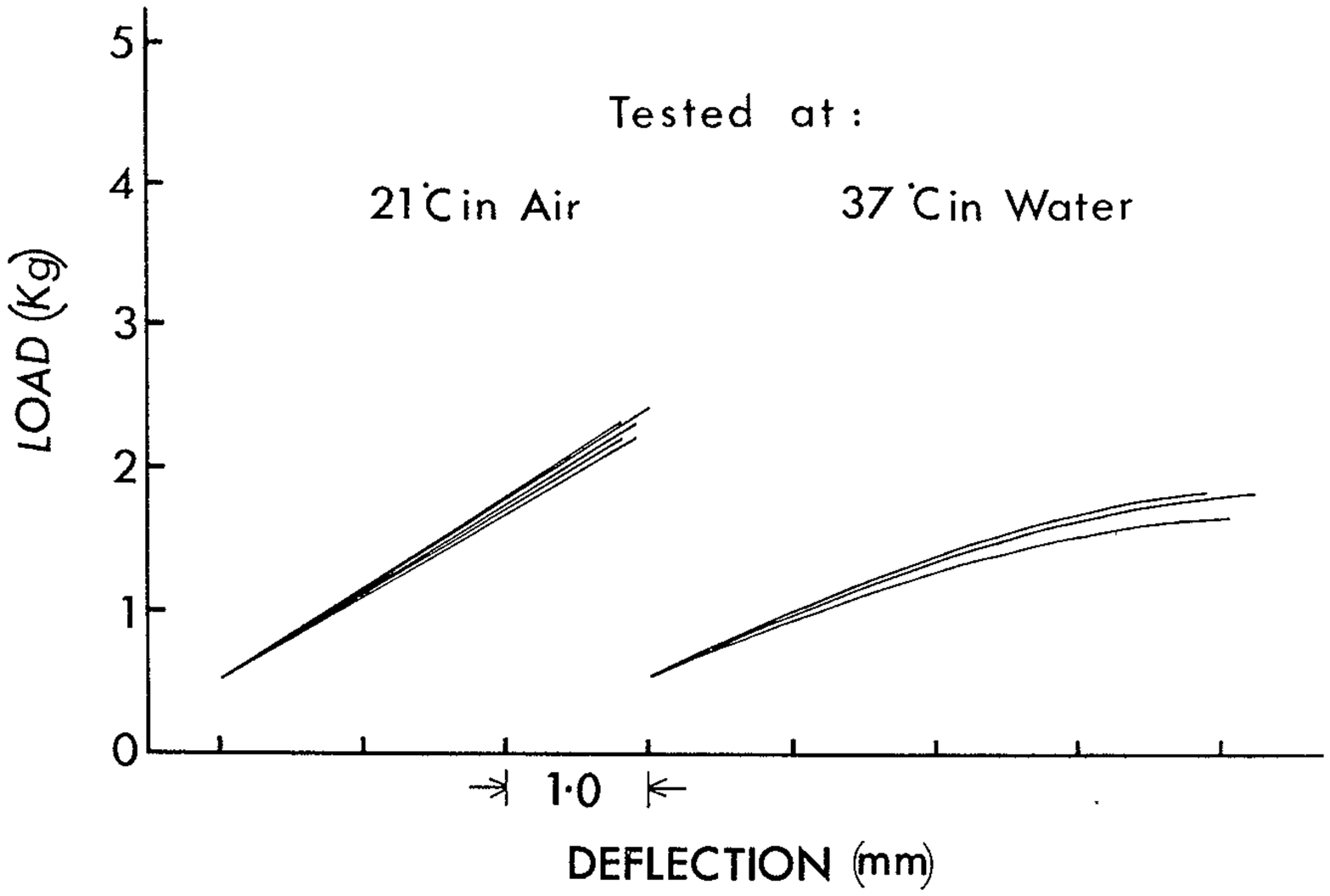


Figure 2-21

Load-deflection graph for Ainsworth Pink.

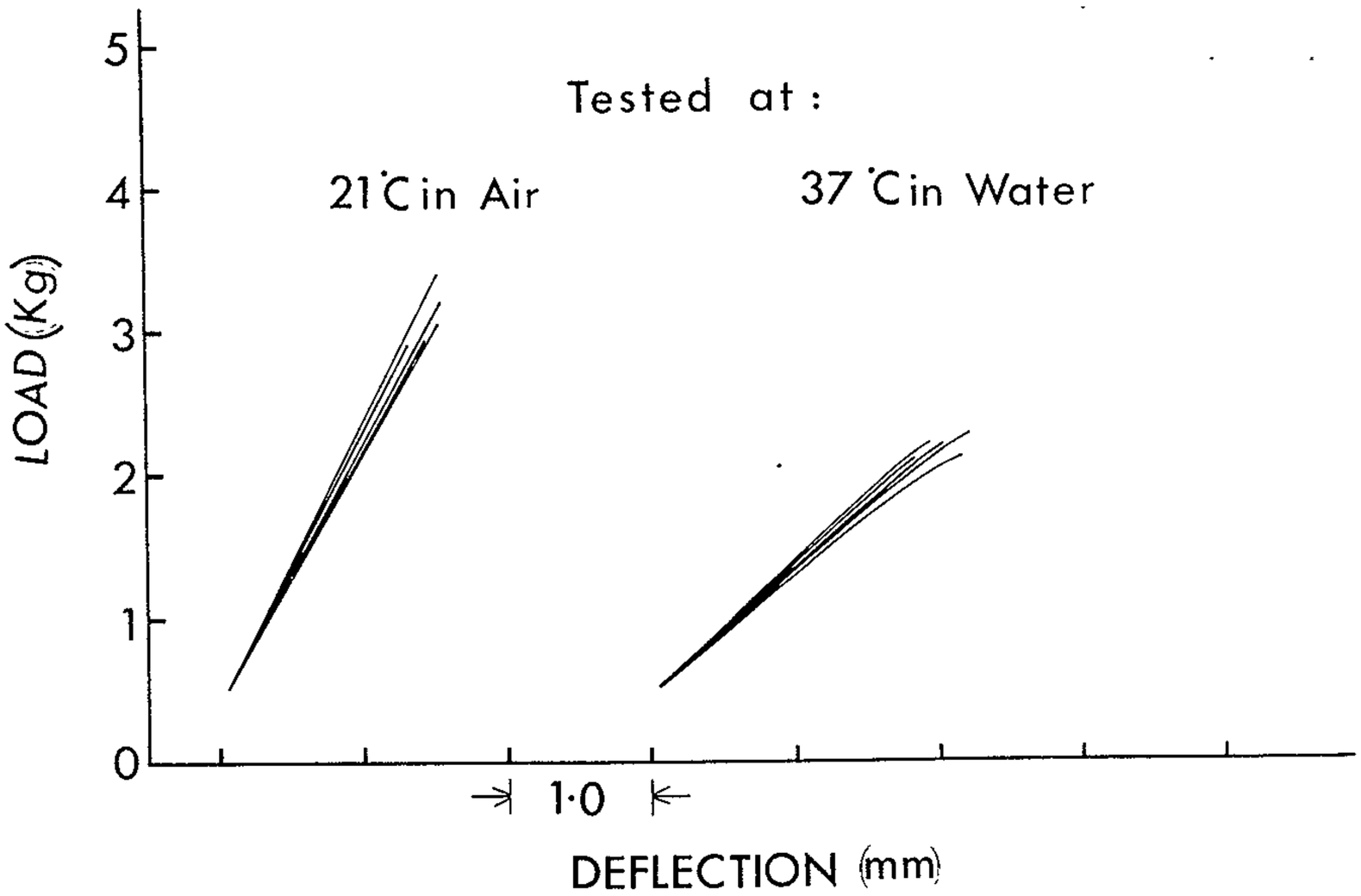


Figure 2-22

Load-deflection graph for Ainsworth Aluminium (Injection moulded).

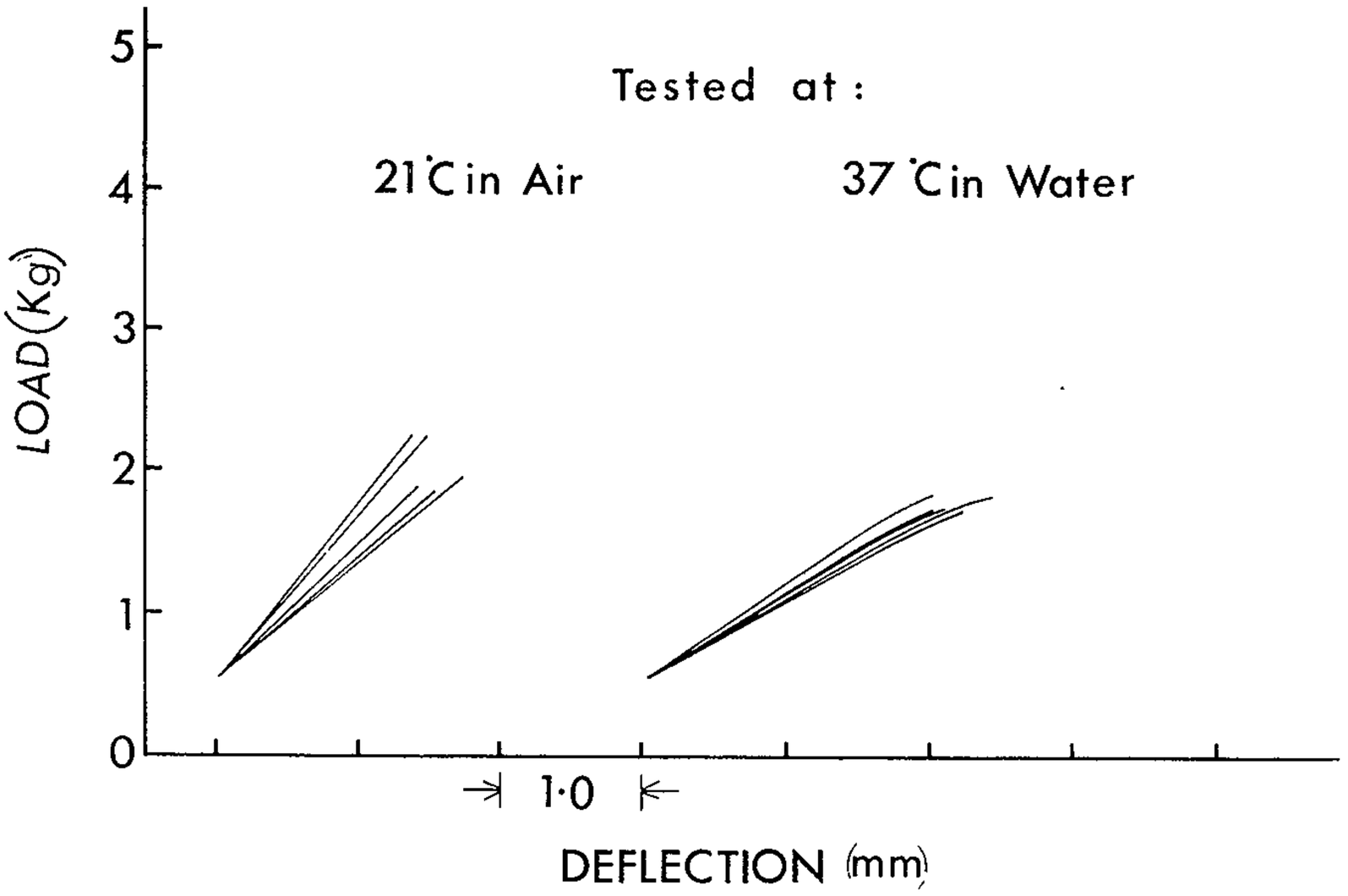


Figure 2-23

Load-deflection graph for Alston Maroon.

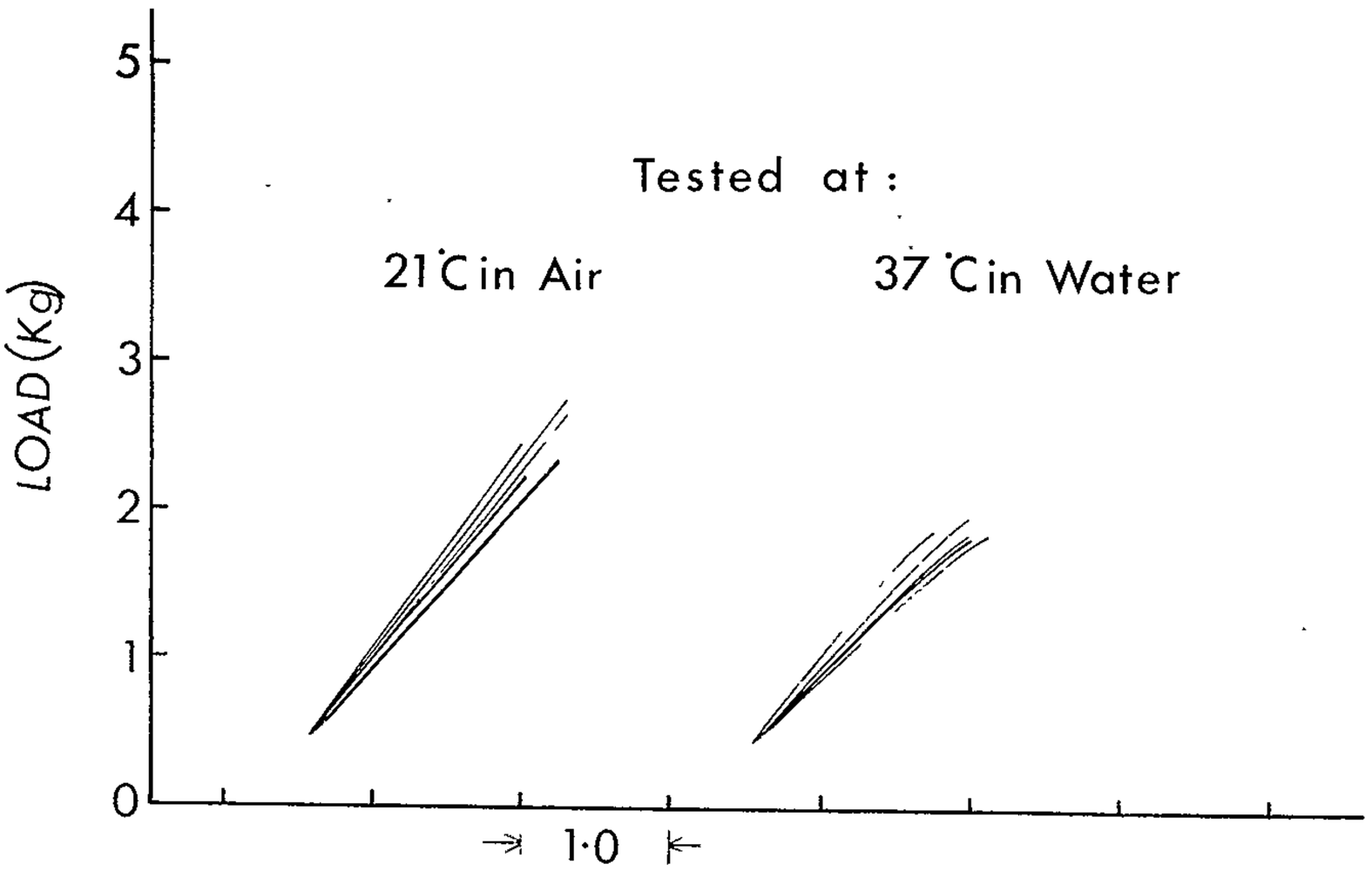


Figure 2-24

Load-deflection graph for Ash Pink.

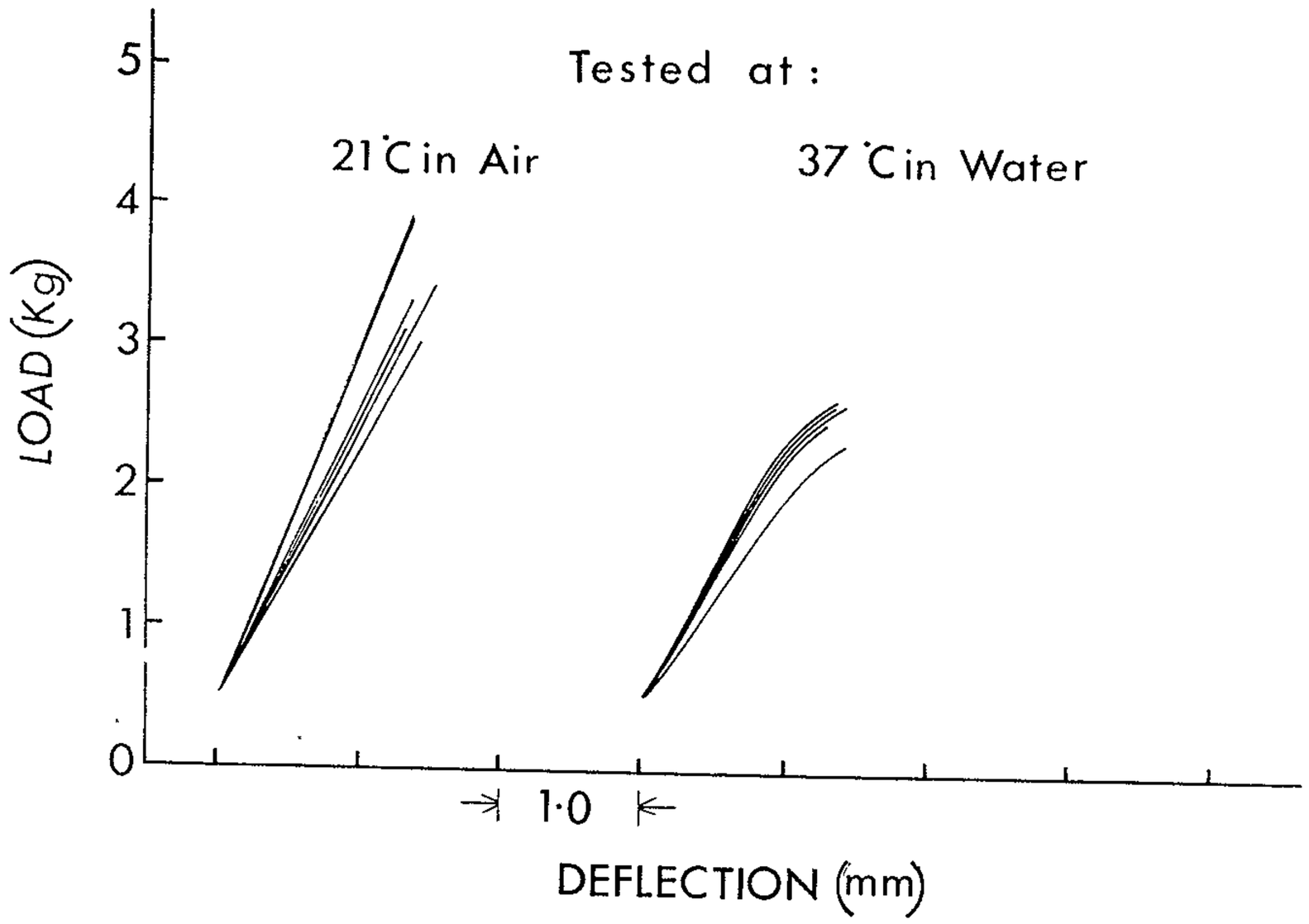


Figure 2-25

Load-deflection graph for Ash Metallized.

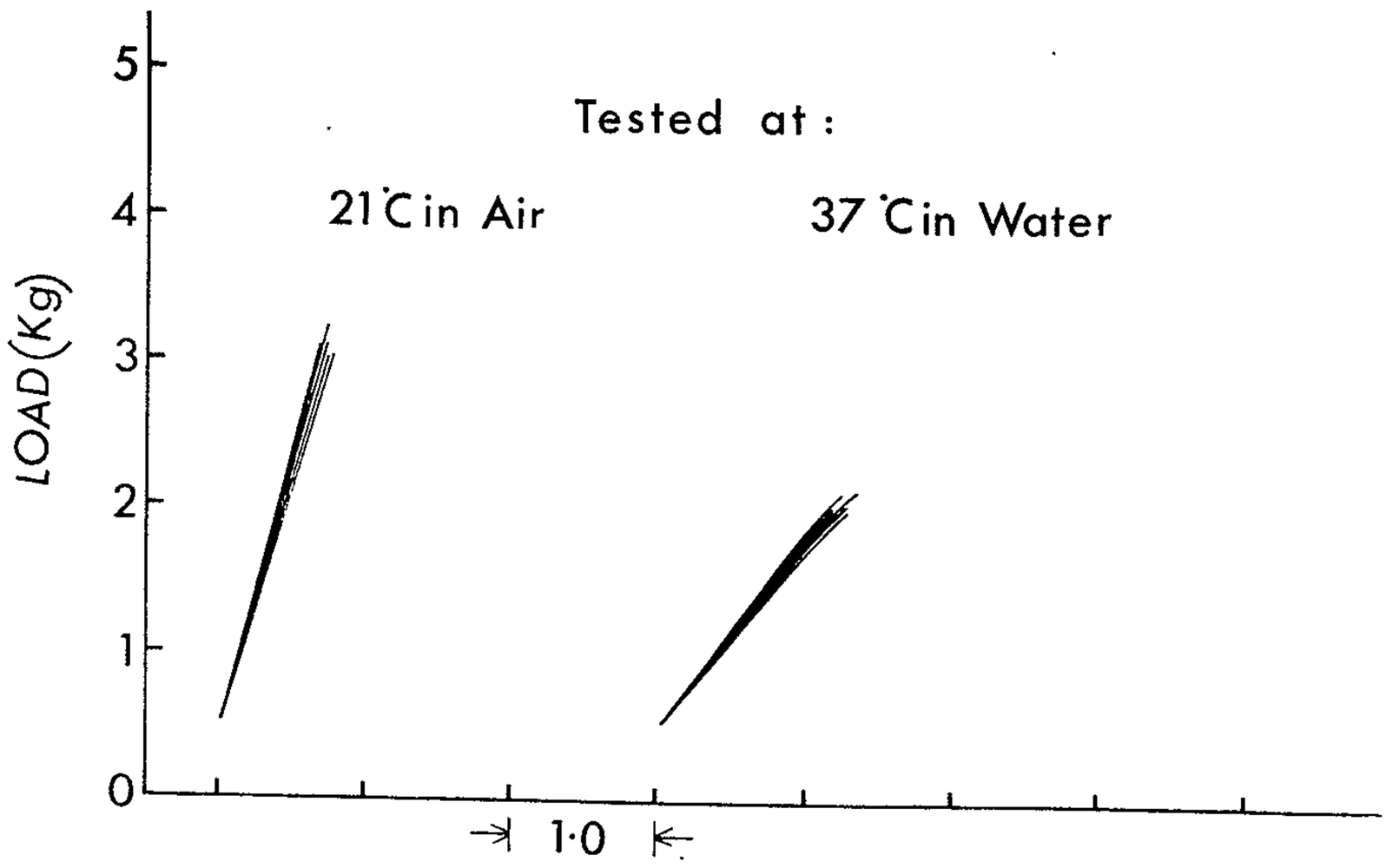


Figure 2-26

Load-deflection graph for Yellow-trays.

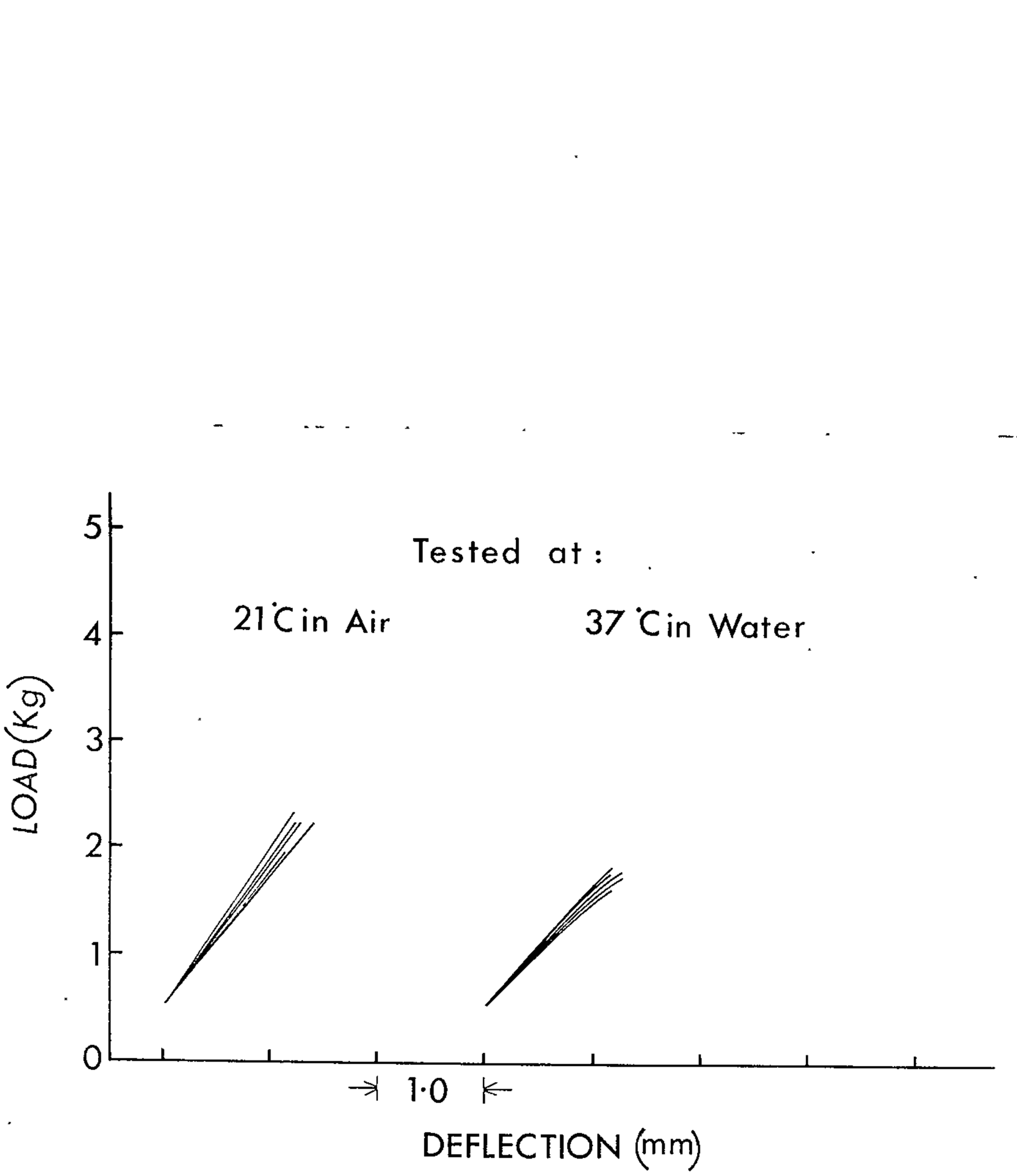


Figure 2-27

Load-deflection graph for Cavex.

TABLE 2-2.

FLOW

Material	Percentage Flow at:							
			60°C		70°C		80°C	
	21°C Air	37°C Water	Air	Water	Air	Water	Air	Water
Impo Brown	< 0.1	1.0	87	87	91	92	93	95
Impo Pink	0.1	1.0	87	86	91	92	94	94
Ainsworth Plastic Aluminium	< 0.1	0.5	86	86	90	91	93	94
Ainsworth Brown (Injection moulded)	0.0	0.0	83	83	89	90	92	93
Ainsworth Pink (Injection moulded)	0.0	0.0	80	82	88	88	91	92
Ainsworth Aluminium (Injection moulded)	0.0	0.0	86	85	91	92	94	95
Alston Maroon	0.0	0.0	75	56	78	78	85	84
Ash Pink	0.0	0.2	80	80	87	88	91	93

TABLE 2-2. (Contd.)

Material	Percentage Flow at:							
			60°C		70°C		80°C	
	21°C Air	37°C Water	Air	Water	Air	Water	Air	Water
Ash Metallized	0.0	0.2	77	79	87	89	90	93
Yellow-trays	0.0	0.7	88	87	94	92	95	96
Cavex	0.0	0.5	83	87	90	93	93	97

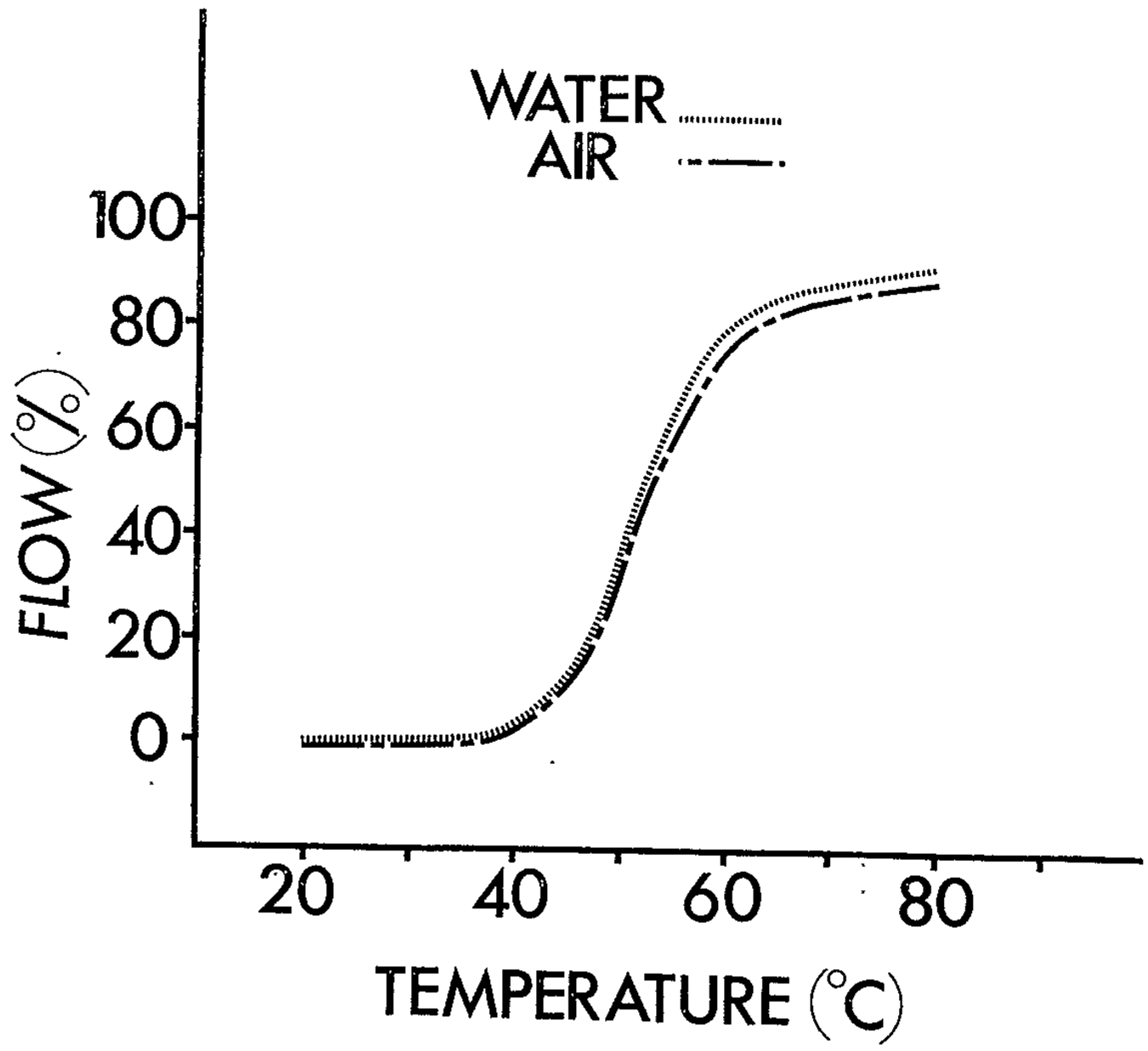


Figure 2-28

Flow: A representative graph for Ash Pink.

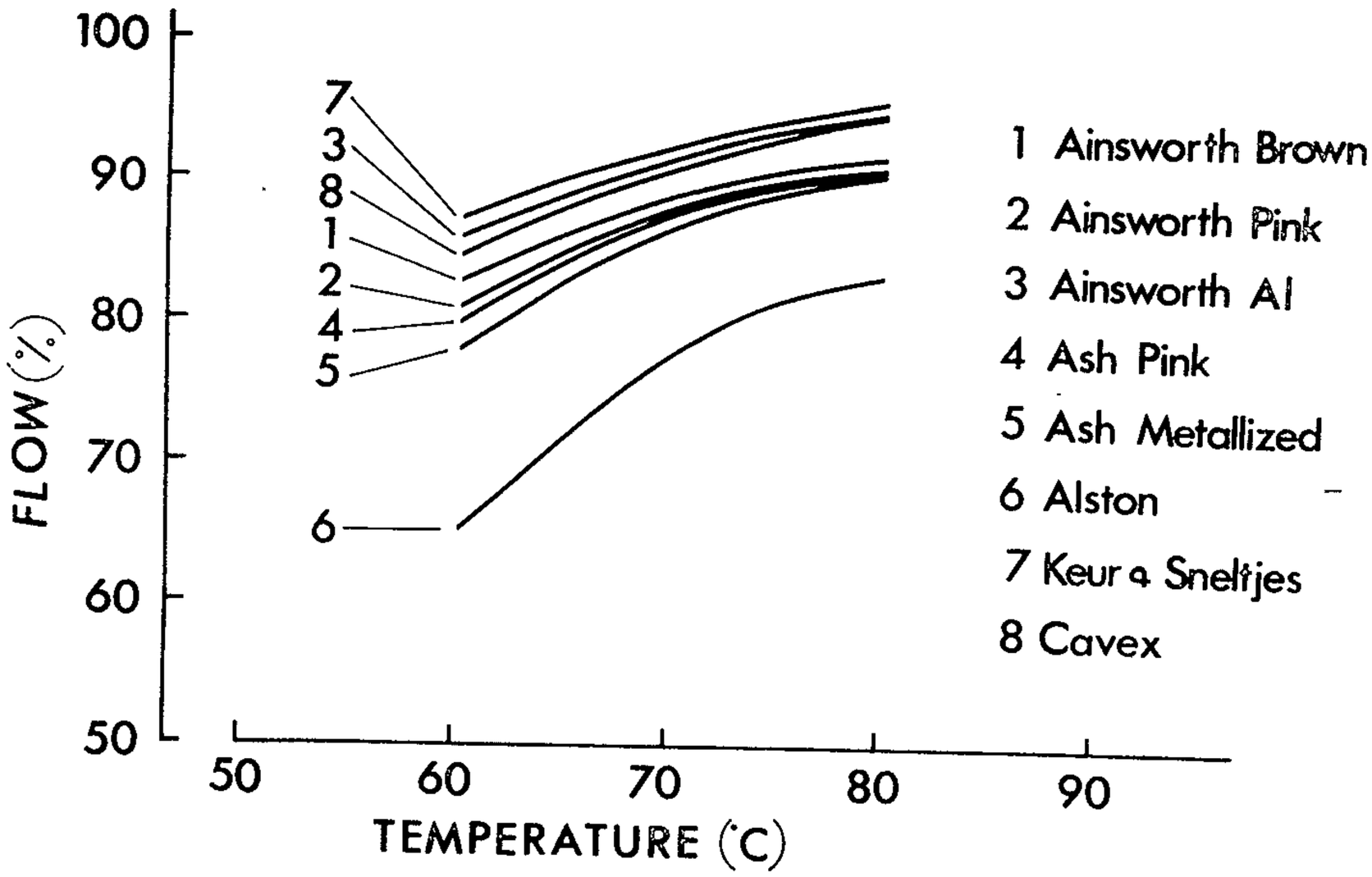


Figure 2-29

The relative flow of the shellac materials from 60 - 80°C.

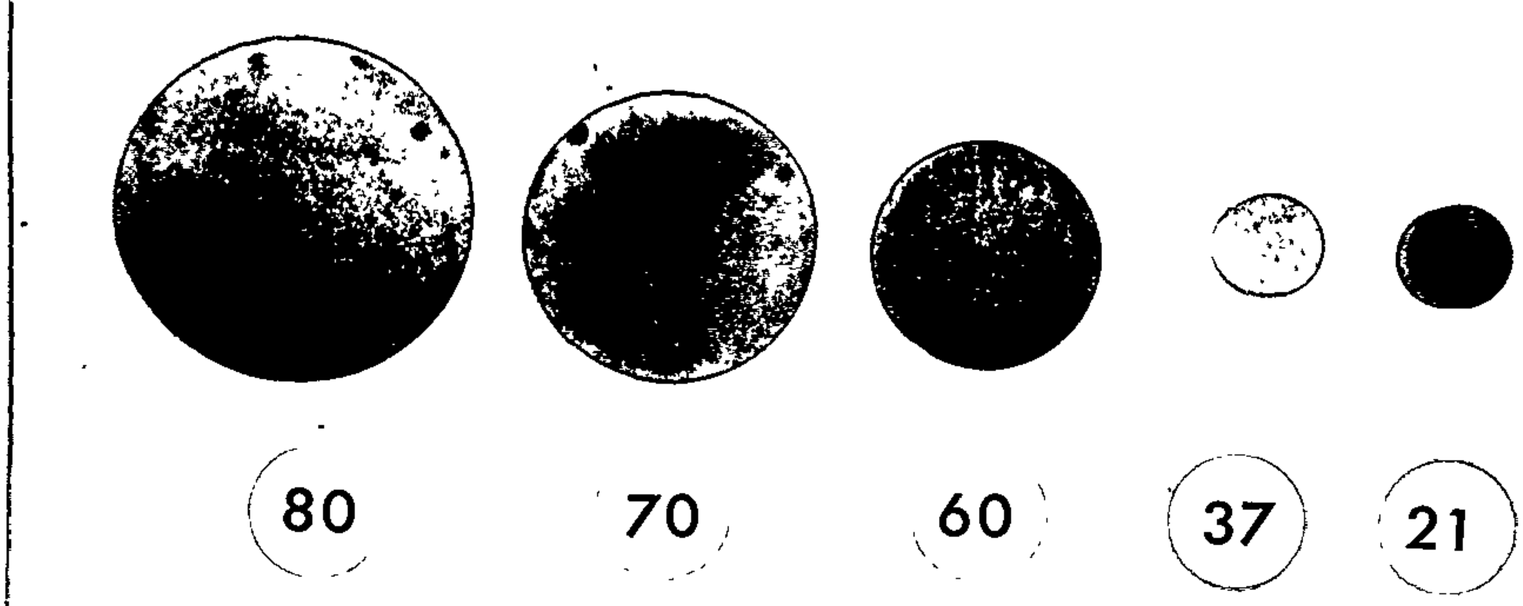


Figure 2-30

Flow specimens tested at temperatures marked.

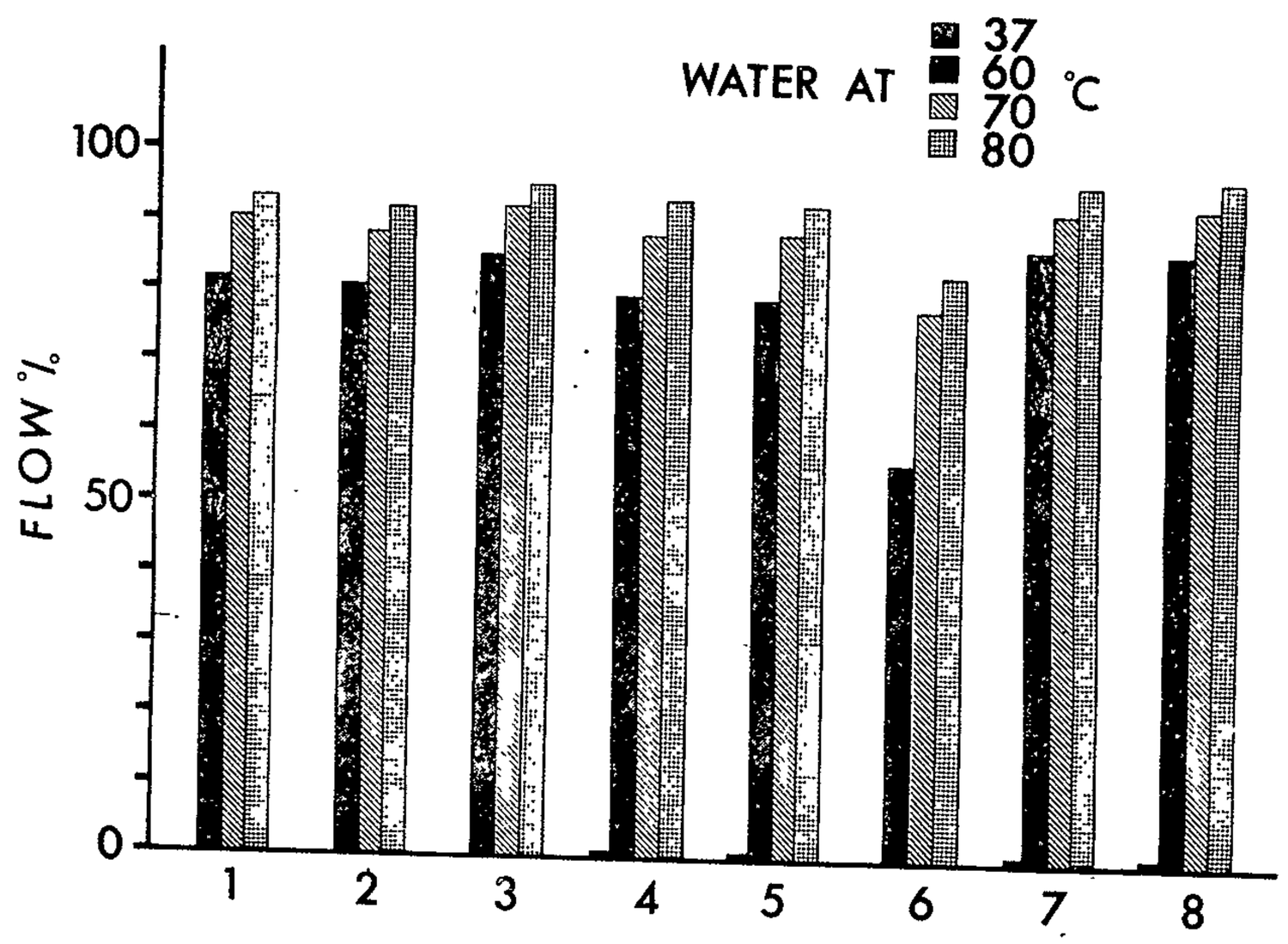
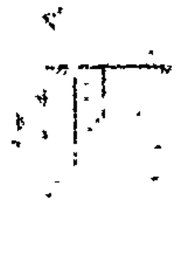


Figure 2-31

1. Ainsworth Brown.
2. Ainsworth Pink.
3. Ainsworth Aluminium.
4. Ash Pink.
5. Ash Metallized.
6. Alston Maroon.
7. Yellow-trays.
8. Cavex.



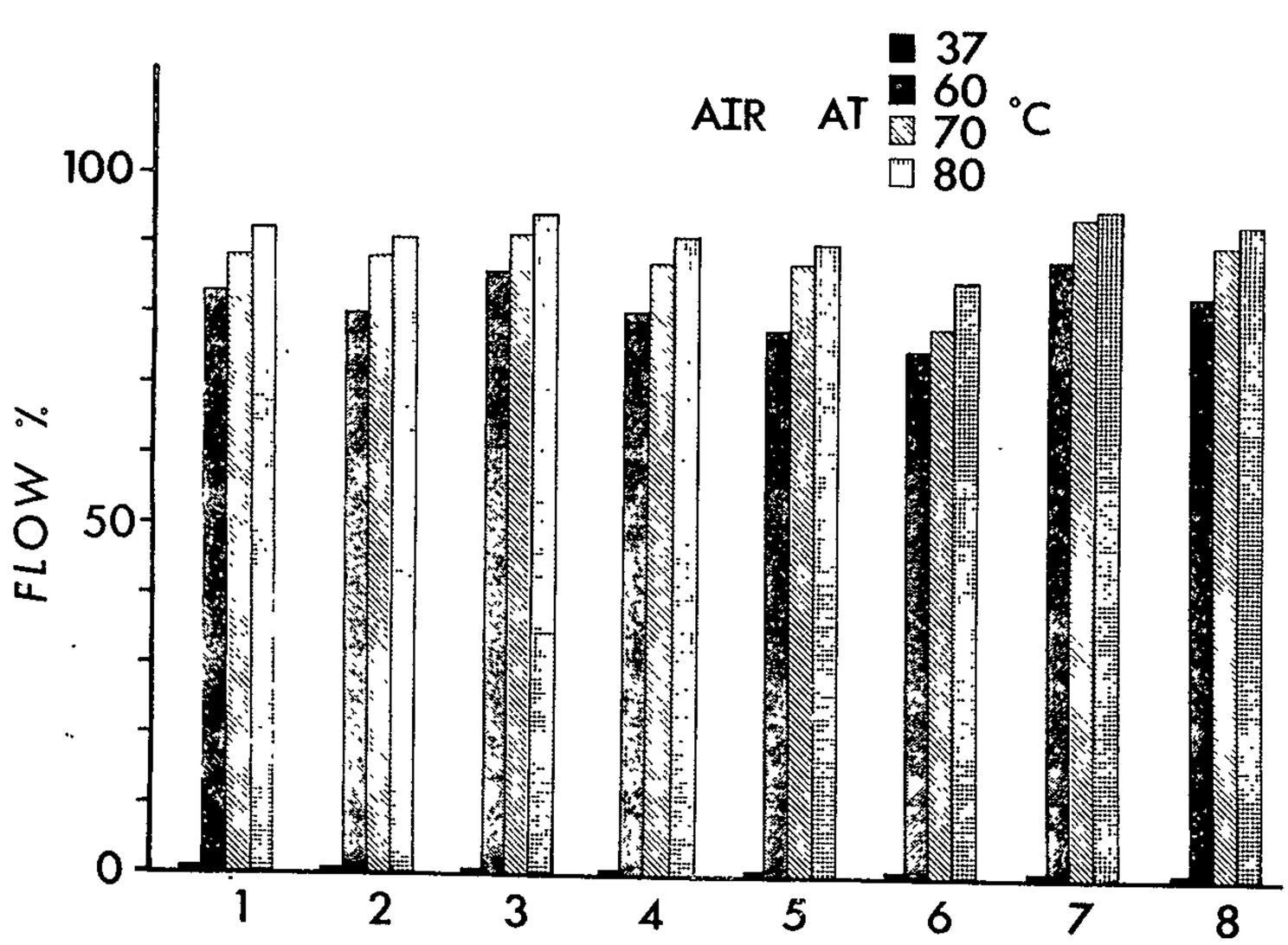


Figure 2-32

1. Ainsworth Brown.
2. Ainsworth Pink.
3. Ainsworth Aluminium.
4. Ash Pink.
5. Ash Metallized.
6. Alston Maroon.
7. Yellow-trays.
8. Cavex.

2.5.3. Dimensional stability:

Measurements of warpage of the moulded baseplates are listed in Tables 2-3 and 2-4. Table 2-3 shows warpage of the baseplate following softening of the blank in water, at the temperature listed, prior to moulding; Table 2-4 shows warpage following softening in dry heat at the temperatures listed. For each material, except where indicated, at least 10 tests were carried out at each softening temperature, and the tables gave the mean values and their standard deviations.

2.5.4. Reproduction of surface detail:

The results of the reproduction of surface detail tests are presented in Table 2-5. A cross (X) indicates that the material showed satisfactory reproduction of detail.

TABLE 2-3.

DIMENSIONAL STABILITY.

(Baseplates moulded after softening in water.)

Material	Warpage(mm) after moulding at:			
	60°C	70°C	80°C	90°C
Impo Brown	1.40 ± 0.10	0.72 ± 0.10	0.55 ± 0.09	0.54 ± 0.10
Impo Pink	0.70 ± 0.08	1.11 ± 0.23	0.47 ± 0.14	0.55 ± 0.16
Ainsworth Plastic Aluminium	0.37 ± 0.05	0.47 ± 0.05	0.30 ± 0.20	0.30 ± 0.08
Ainsworth Brown (Injection moulded)	1.43 ± 0.12	0.28 ± 0.08	0.23 ± 0.07	0.24 ± 0.06
Ainsworth Pink (Injection moulded)	0.34 ± 0.10	0.16 ± 0.06	0.17 ± 0.04	0.26 ± 0.04
Ainsworth Aluminium (Injection moulded)	0.06 ± 0.08	0.43 ± 0.13	0.18 ± 0.09	0.17 ± 0.03
Alston Maroon	Did not mould	0.61 ± 0.14	0.44 ± 0.07	0.41 ± 0.14
Ash Pink	Did not mould	0.44 ± 0.10	0.39 ± 0.06	0.30 ± 0.07
Ash Metallized	Did not mould	0.64 ± 0.10	0.36 ± 0.06	0.31 ± 0.05
Yellow-trays	0.46 ± 0.15	0.37 ± 0.08	0.24 ± 0.06	0.23 ± 0.07
Cavex	Did not mould	0.64 ± 0.20	0.36 ± 0.07	0.34 ± 0.15

TABLE 2-4.

DIMENSIONAL STABILITY.

(Baseplates moulded after softening in air.)

Material	Warpage(mm) after moulding at: 60°C	70°C	80°C	90°C
Impo Brown ✱	1.52 ± 0.10	0.83 ± 0.10	0.62 ± 0.10	0.47 ± 0.05
Impo Pink ✱	1.44 ± 0.10	0.44 ± 0.10	0.50 ± 0.10	0.47 ± 0.20
Ainsworth Plastic Aluminium ✱	0.53 ± 0.14	0.28 ± 0.05	0.27 ± 0.05	0.22 ± 0.05
Ainsworth Brown (Injection moulded)	1.59 ± 0.20	0.68 ± 0.13	0.49 ± 0.05	0.20 ± 0.05
Ainsworth Pink (Injection moulded)	1.34 ± 0.23	0.61 ± 0.20	0.58 ± 0.12	0.20 ± 0.04
Ainsworth Aluminium (Injection moulded)	0.26 ± 0.13	0.25 ± 0.10	0.22 ± 0.03	0.17 ± 0.06
Alston Maroon	Did not mould	0.59 ± 0.10	0.20 ± 0.10	0.20 ± 0.09
Ash Pink	Did not mould	0.78 ± 0.30	0.33 ± 0.06	0.13 ± 0.03
Ash Metallized	Did not mould	0.48 ± 0.06	0.36 ± 0.07	0.13 ± 0.01
Yellow-trays	0.47 ± 0.13	0.26 ± 0.02	0.09 ± 0.03	0.10 ± 0.04
Cavex	Did not mould	0.28 ± 0.08	0.14 ± 0.04	0.11 ± 0.02

✱ Five tests only at each temperature.

TABLE 2-5.

REPRODUCTION OF SURFACE DETAIL.

Material	Temperature of the test (°C): 60 A	60 W	70 A	70 W	80 A	80 W
Impo Brown	X	X	X	X	X	X
Impo Pink	X	X	X	X	X	X
Ainsworth Plastic Aluminium	X	X	X	X	X	X
Ainsworth Brown (Injection moulded)	X	X	X	X	X	X
Ainsworth Pink (Injection moulded)	X	X	X	X	X	X
Ainsworth Aluminium (Injection moulded)	X	X	X	X	X	X
Alston Maroon	•	•	•	•	X	X
Ash Pink	•	•	X	X	X	X
Ash Metallized	•	•	X	X	X	X
Yellow-trays	X	X	X	X	X	X
Cavex	•	•	X	X	X	X

In each case, column A shows results when baseplates softened in air, column W when softened in water.

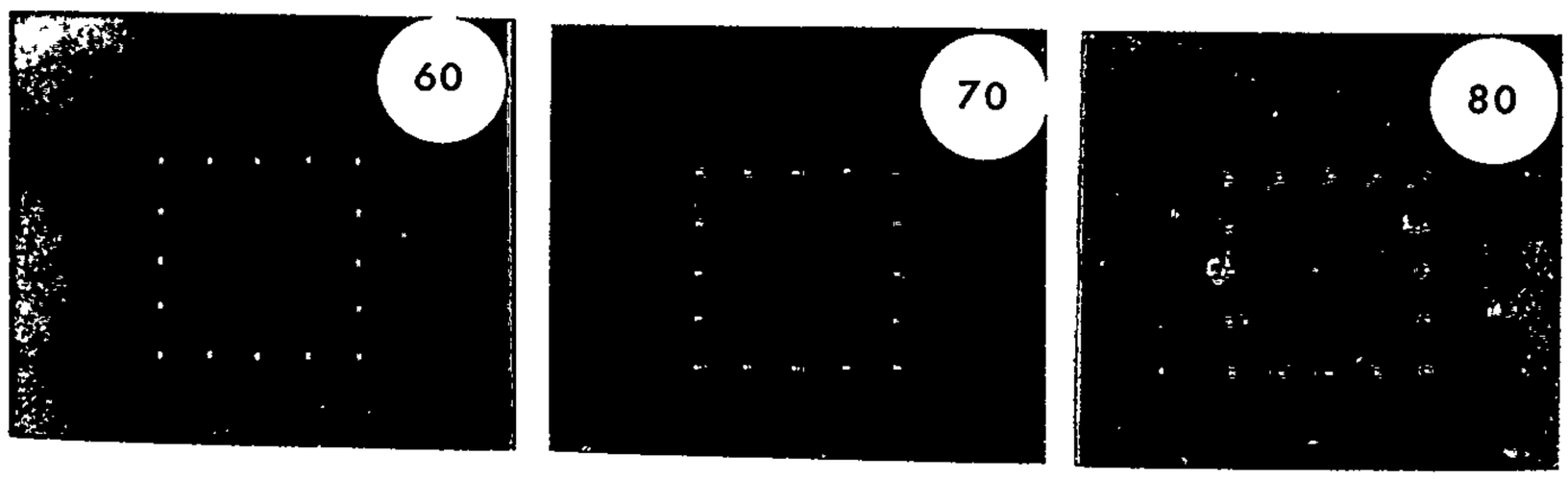


Figure 2-33

Reproduction of surface detail specimens for Ainsworth Pink; the blanks were softened at the temperatures marked.

2.6. DISCUSSION.

2.6.1. Transverse strength and rigidity:

It can be seen from the graphs in Figures 2-17 to 2-27, that the shellac materials tested were substantially elastic at 21°C in air, indicated by load-deflection curves which were straight lines up to the fracture point. At 37°C all materials showed plastic deformation at higher loads, indicated by non-linear sections at the upper ends of the load-deflection curves. Also, there was a marked reduction in strength of all materials at 37°C.

There was a wide range, both in stiffness and in the fracture load, amongst the different materials. This could to some extent be attributed to the variation in thickness of the baseplate blanks, and thus in the thickness of specimens prepared from different materials. The thickness of blanks for any one material did not vary by more than 0.005 mm, but there was a range in thickness of 1.4 mm to 2.0 mm amongst the different materials. Therefore the results in Table 2-1 should not be used to compare directly the strengths of the different shellac materials themselves. Instead only the transverse strengths of actual baseplate blanks, and by inference, of baseplates prepared from them, can be compared. Similar reservations apply to comparisons of rigidity amongst the different materials.

There is a difference in transverse strength between the group of three new injection moulded Ainsworth baseplate blanks, and the group of former Ainsworth products (Impo Brown, Impo Pink and Ainsworth Plastic Aluminium). The Ainsworth Brown and Pink baseplate blanks show far more deflection at 37°C than Impo Brown and Pink, and while the blanks of Ainsworth Pink are stronger than those of Impo Pink, the difference in strength between blanks of Ainsworth Brown and Impo Brown is slight.

However, the injection moulded Aluminium blanks are markedly stronger and more rigid than the earlier Ainsworth Plastic Aluminium blanks.

Baseplate blanks of Ash Metallized were the strongest and amongst the stiffest at 21°C in air, and were also the strongest and stiffest at 37°C in water.

2.6.2. Flow:

It was found that the results of flow tests at any temperature were similar, whether the tests were done in air or under water. The graph shown in Figure 2-28 represents the relationship between temperature and flow for Ash Pink. One curve is for tests in air, the other for tests under water, and this is typical of the results for all materials tested.

The histograms (Figures 2-31, 2-32) indicate the

relative flow of the various materials at 37, 60, 70 and 80°C.

Obviously these materials need a very low flow at room temperature or at 37°C, so that they will resist, without permanent deformation, the forces exerted on them in the mouth or in the laboratory. At the same time there should be a sufficiently high flow at a convenient softening temperature to allow moulding with the fingers. A flow of 80 per cent should be adequate for satisfactory moulding, and most of the materials attained that flow at 60°C. Alston was the only exception here; its flow did not exceed 80 per cent until a temperature of 80°C was reached, and in fact this material was found to be difficult to mould satisfactorily.

However, the results obtained in the following section suggest that measurements of flow at high temperatures do not by themselves give a satisfactory indication of the moulding properties.

2.6.3. Dimensional stability:

Flow tests are a measure of the plasticity of a material, and therefore flow at high temperatures is often regarded as a measure of "mouldability" of thermoplastic materials. It might have been predicted then, from the flow tests on the shellac baseplate materials, that the results of warpage measurements would be similar on baseplates moulded

after softening in water or in air, since this did not affect flow. Similarly, it might have been predicted that all materials except Alston Maroon should mould satisfactorily at 60°C or higher, since they attained a flow of at least 80 per cent at these temperatures, and that for all materials, stress relief would be greatest in baseplates moulded at 60°C and decrease as the moulding temperature increased.

However, it was found that many materials would not mould satisfactorily at 60°C, which would suggest that flow tests alone are not a guide to moulding properties. All materials did mould satisfactorily at 70°C, whether softened in water or in air.

In general, warpage from stress relief was highest at the lowest moulding temperature and decreased as the moulding temperature increased. For the more stable materials, the palatal warpage measured was of the order of 0.5 mm when moulded at 70°C, decreasing to about 0.2 mm at 80 and 90°C. From the histograms in Figures 2-34 and 2-35, it can be seen that only four materials moulded at 60°C, and the decrease in height of the bars for each material (more marked in some than in others), indicates a decrease in warpage that follows an increase in moulding temperature. However, it was found that the results were quite different when the baseplates were moulded after softening in water, when compared with similar

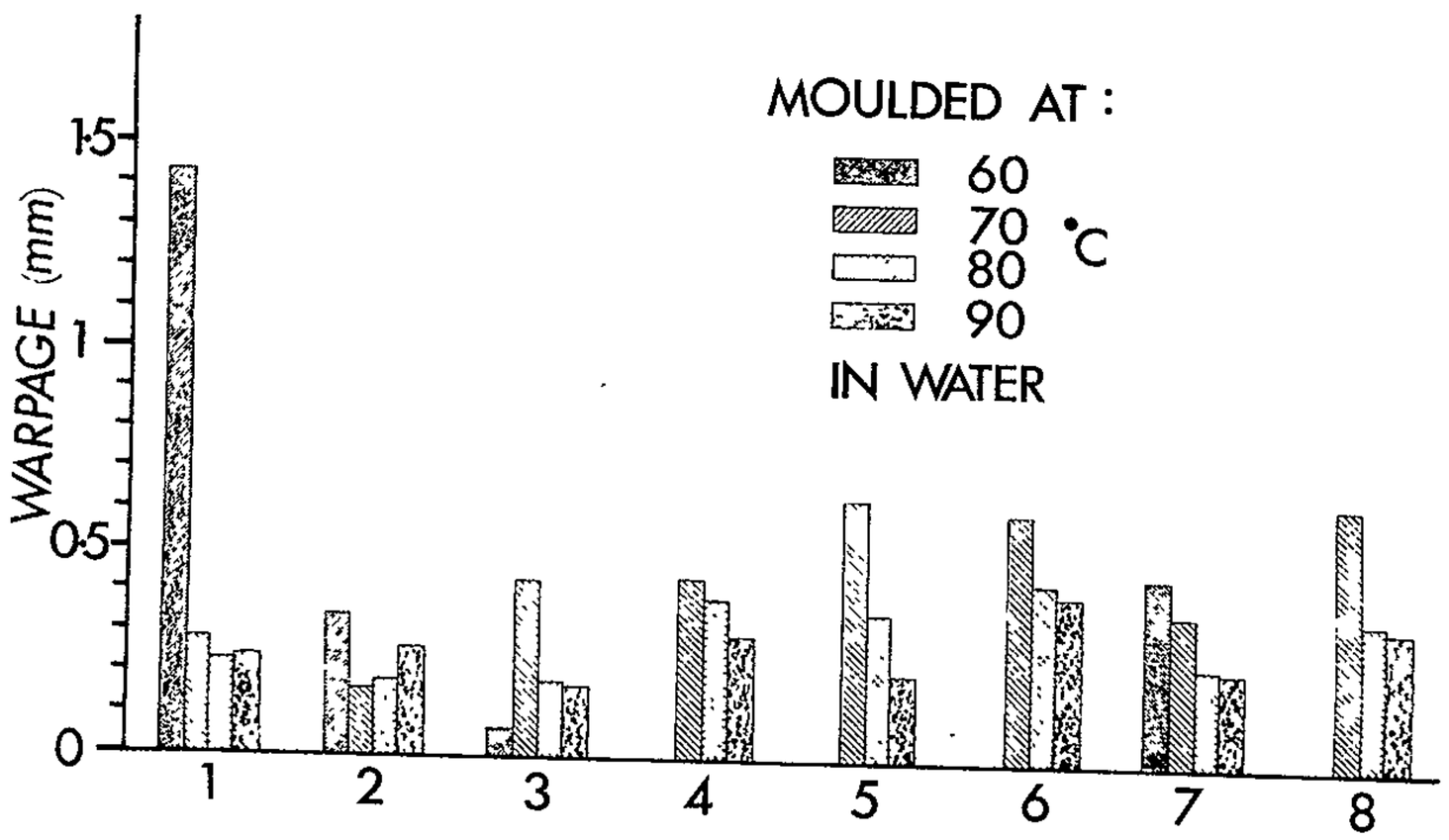


Figure 2-34

1. Ainsworth Brown.
2. Ainsworth Pink.
3. Ainsworth Aluminium.
4. Ash Pink.
5. Ash Metallized.
6. Alston Maroon.
7. Yellow-trays.
8. Cavex.

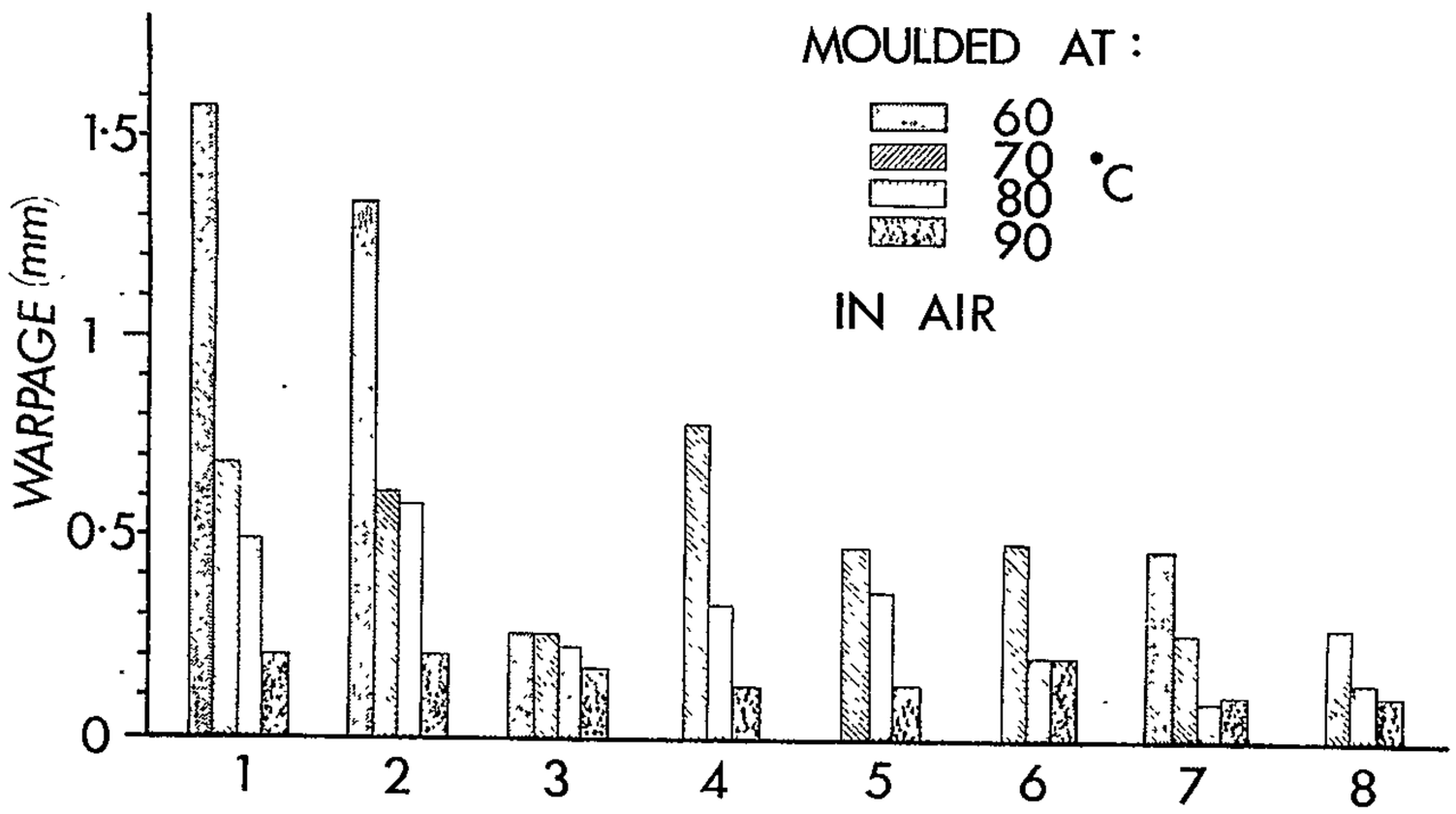


Figure 2-35

1. Ainsworth Brown.
2. Ainsworth Pink.
3. Ainsworth Aluminium.
4. Ash Pink.
5. Ash Metallized.
6. Alston Maroon.
7. Yellow-trays.
8. Cavex.

baseplates softened in air. Some materials were more dimensionally stable if softened in water before moulding, and others if they were softened in air.

One outstanding anomaly was provided by the injection moulded Ainsworth Aluminium blanks. This material moulded very well at 60°C, and if it was softened in water at 60°C it showed the least warpage due to stress relief, of any material moulded at any temperature. The mean warpage was only 0.06 mm, which is negligible. However, when the material was softened in water at 70°C before moulding, the mean warpage resulting from stress relief was 0.45 mm, an increase of over 700 per cent. At 80°C and 90°C the warpage decreased to 0.2 mm, which is still much higher than the warpage after moulding at 60°C. The manufacturer of this material[23] suggested that at temperatures greater than 60°C, the aluminium filler may react with the stearic acid plasticiser, forming an aluminium stearate; this reaction may stiffen the baseplate and cause difficulty in moulding, and so lead to greater stress relief after moulding. However, the material does not behave in this anomalous manner if it is softened in air before moulding.

The behaviour of shellac baseplate materials in general is what one might predict: highest warpage due to stress relief when moulded at 60°C, decreasing as the moulding temperature increases.

Of all the materials tested, the most dimensionally stable baseplates were moulded from Ainsworth Aluminium injection moulded material, softened in water at 60°C. This was followed by Ash Metallized when softened in air at 90°C, and Keur and Sneltjes materials softened in air at 80 and 90°C. The latter materials show a very small palatal warpage at both 80 and 90°C, and thus in practice the softening temperature would not be critical. However, the only general conclusion to be drawn from these measurements of warpage, is that manufacturers of shellac baseplates should recommend a definite softening method and softening temperature for their materials.

2.6.4. Reproduction of surface detail:

Table 2-5 shows that all the materials except Alston were satisfactory when softened at 70 and 80°C, and some were satisfactory at 60°C as well. Alston Maroon failed the test at 60 and 70°C, but showed satisfactory reproduction of detail at 80°C.

There was no apparent difference in reproduction of detail whether the material was softened in air or water, except with the injection moulded Ainsworth baseplates, which seemed to give better reproduction when softened in water. Due to the nature of the test, which only required a qualitative assessment of reproduction of detail, this difference was not measured quantitatively. However, this observation correlates with the

results of dimensional stability tests (Section 2.6.3), in that this material is slightly more plastic when softened in water than in air at the same temperature. This was indicated by a lower warpage due to stress relief on all injection moulded Ainsworth specimens softened in water at 60°C before moulding, and on Ainsworth Brown and Pink specimens softened at 70°C before moulding.

With dental impression compounds, there is a definite relationship between reproduction of surface detail and flow. Bevan and Smith[24] found that there was a minimum value of 83 per cent for flow of dental impression compound, below which the material did not pass the reproduction of surface detail test described in the Specifications for this material[18,19]. When the flow exceeded 83 per cent, all materials passed the test.

The reproduction of surface detail test for the shellac materials, described in Section 2.4.4, is quite different from the one specified for impression compound. However, it did provide a satisfactory qualitative assessment of reproduction of detail. It can be seen by comparing the results in Table 2-2 (page 60) and Table 2-5 (page 69), that a correlation between reproduction of surface detail and flow does not appear to exist for the shellac materials.

CHAPTER 3

THERMO-SOFTENING SYNTHETIC RESIN MATERIALS.

3.1. INTRODUCTION.

The thermo-softening synthetic resin materials tested are listed in Table 1-1 (page 4), together with the names of their manufacturers. They are supplied as preformed blanks which are manipulated in a similar manner to the shellac materials, except that heating at far higher temperatures is necessary to render these materials adequately plastic.

The materials were identified by Dr. F. L. Connors[25], Senior Lecturer in Polymer Science, University of New South Wales, and Table 3-1 lists the materials, their composition, and some relevant physical properties.

TABLE 3-1

Material	Composition	Density	Water Sorption (Per cent per 24 hours)
Keba-Plast	Cellulose acetate	-	1.9 - 6.5
Heko-Werk	Polystyrene (Extruded and cut off)	1.098	0.03 - 0.4
Bayer	Polystyrene (Prepared as a cast film)	1.036	0.03 - 0.4

3.2. DEVELOPMENT OF TESTING METHODS.

Like the shellac materials described in Chapter 2, these materials were supplied as preformed blanks which were softened by heating before being moulded. In general, it was found that the various tests whose development is described in Section 2.2 (page 8) could be applied directly to these materials.

Preparation of flow specimens was difficult. The shellac materials had been moulded after softening in an iron crucible, in an oven at 90°C, for 7 - 12 minutes. It was found that similar heating did not soften any of these materials sufficiently. Therefore the oven temperature was raised in steps of 10°C, and it was found that Keba-Plast could be moulded after heating at 160°C for 10 minutes. The other two materials had to be heated to 180°C for the same time before they were sufficiently plastic. Heating Keba-Plast to 180°C caused a brownish discolouration; therefore flow specimens were moulded from this material after it had been softened at 160°C, while the other two materials were heated to 180°C. In all cases, after the particular material had been held at its softening temperature for 10 minutes, it was forced into the mould shown in Figure 2-6 (page 20), with a spatula.

In the case of tests for dimensional stability,

it was found that the baseplate blanks had to be softened at 100°C before they could be successfully moulded. Softening in air or in water for 10 minutes at this temperature gave equally good adaptation, but it was found that after 10 minutes in water at 100°C Keba-Plast developed a clouded appearance. This was caused by water sorption[25], and it will be noted in Table 3-1 that this material has a high water sorption. Since the manufacturers of Keba-Plast and Bayer materials recommend dry heat, and the manufacturer of Heko-Werk makes no recommendation, it was decided to soften the blanks of all three materials in an oven at 100°C for 10 minutes, before moulding specimens for dimensional stability tests.

It was decided not to attempt to make dimensional stability tests with the materials softened at temperatures any higher than 100°C. At this temperature, handling of the blanks was difficult even though rubber gloves were worn. Since in the laboratory these materials would probably be adapted to a cast by finger pressure, it was felt that the results of tests following softening the blank at temperatures above 100°C would not be of practical importance.

In the case of reproduction of surface detail, all three materials failed the test described in Section 2.4.4. This test had deliberately been made as selective as possible

(page 35), and this indicated that these materials as a group would show poor reproduction of detail when compared with most of the shellac materials.

As a matter of interest, the test described in Section 2.4.4 was modified by increasing the load and its time of application, to see whether these materials could pass the test under more favourable conditions. However, even when a load of 10 kg was applied for 10 minutes, none of these materials reproduced any of the holes in the die.

3.3. APPARATUS.

The apparatus used for each of the tests (transverse strength and rigidity, flow, dimensional stability and reproduction of surface detail), was the same as that used for similar tests with the shellac materials; each is described in detail in the respective sub-section of Section 2.3 (page 35).

3.4. EXPERIMENTAL METHOD.

3.4.1. Transverse strength and rigidity:

Specimens were prepared from the widest section of a baseplate blank using a scalpel and a 2.5 cm wide metal rule. The baseplate was scored with the scalpel along the edges of the rule, and the excess material was carefully broken away. Minor

adjustments to the width of the specimens were made with 220A silicon carbide abrasive paper and checks were made with vernier calipers until each specimen was 2.50 ± 0.01 cm wide. The length of the specimen was at least 6.0 cm, so that it would span the supports of the testing machine.

The specimen was placed across the supports of the testing machine, and the load was increased from an initial zero load at the rate of 1500 gm/minute until fracture of the specimen occurred. Readings of deflection were taken every five seconds, so that load-deflection curves could be drawn for each material.

3.4.2. Flow:

Specimen preparation was by the method described in Section 2.4, except that the softening temperatures were higher. Softening of the material in order to make flow specimens was carried out in an oven; Keba-Plast was softened at 160 ± 1°C for 10 minutes, and Heko-Werk and Bayer were softened at 180 ± 1°C for the same time.

Flow tests were made by the method described in Section 2.4.2 (page 47). The tests were done in air at 21 ± 1°C, and in water at 37 ± 1°C.

3.4.3. Dimensional stability:

The baseplate blank was softened by heating for 10 minutes in an oven at 100°C; specimen preparation then followed the method described in Section 2.4.3 (page 49). The test for dimensional stability also followed exactly the method described in Section 2.4.3.

However, after measurements had been made of the palatal warpage after two hours' immersion in water at 37 ± 1°C, a second series of tests was made, in which warpage was measured by the same method, after three days' immersion in water at the same temperature.

3.4.4. Reproduction of surface detail:

The experimental method was the same as described in Section 2.4.4 (page 50) except that all materials were softened for 10 minutes in an oven at 100 ± 1°C.

3.5. RESULTS.

3.5.1. Transverse strength and rigidity:

The results of the transverse tests for strength and rigidity are presented in Table 3-2. Load-deflection graphs for the different materials tested are illustrated in Figures 3-1 to 3-3.

TABLE 3-2.

TRANSVERSE STRENGTH & RIGIDITY.

Material	Temp. of Test (°C)	No. of Tests	Thickness of Specimen (mm)	Average Deflection (mm) at 1500 gm	at 2000 gm	at 2500 gm	maximum deflection	Fracture Load (kg)
Keba-Plast	21	5	1.0	4.5	7.0	-	20.0	2.4 ⁂
	37	5	1.0	4.5	7.0	-	20.0	2.4 ⁂
Heko-Werk	21	5	1.0	9.0	-	-	9.0	1.5
	37	5	1.0	-	-	-	9.0	1.0
Bayer	21	5	1.2	3.7	7.2	-	7.2	2.0
	37	5	1.2	9.0	-	-	9.0	1.5

⁂ The specimen did not fracture under this load, but deflection to the maximum extent possible in the machine.

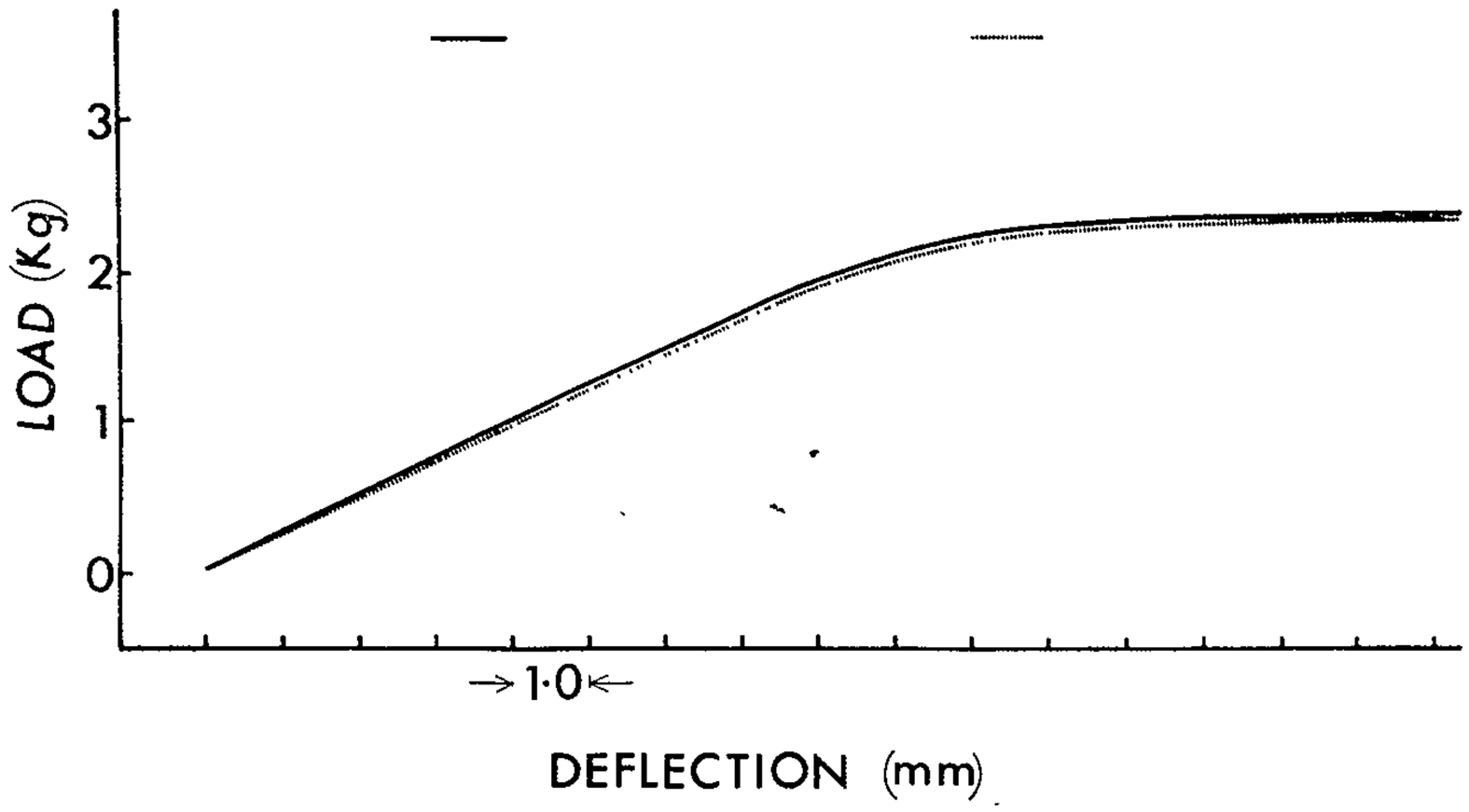


Figure 3-1

Load-deflection graph for Keba-Plast.

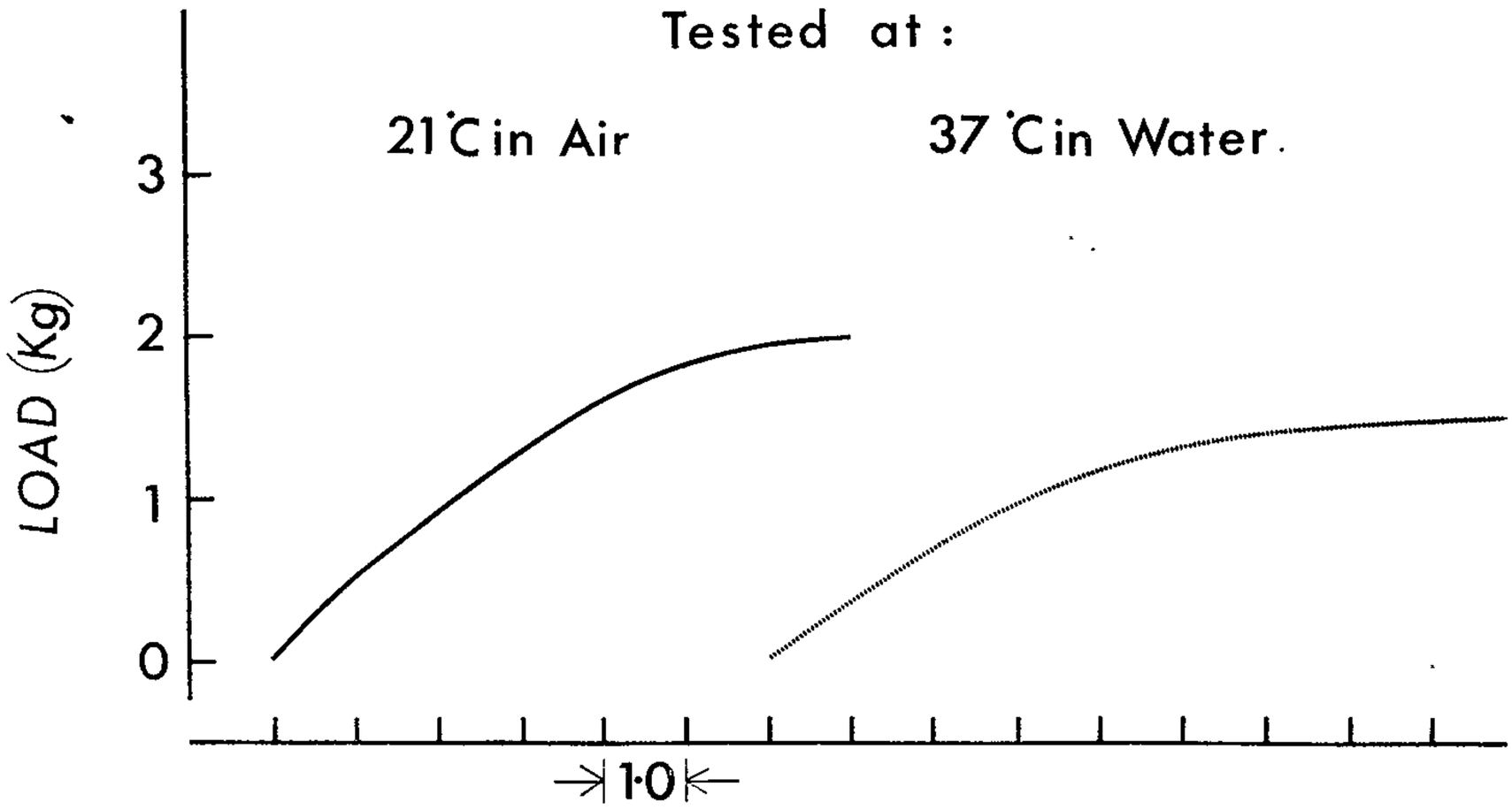


Figure 3-2

Load-deflection graph for Heko-Werk.

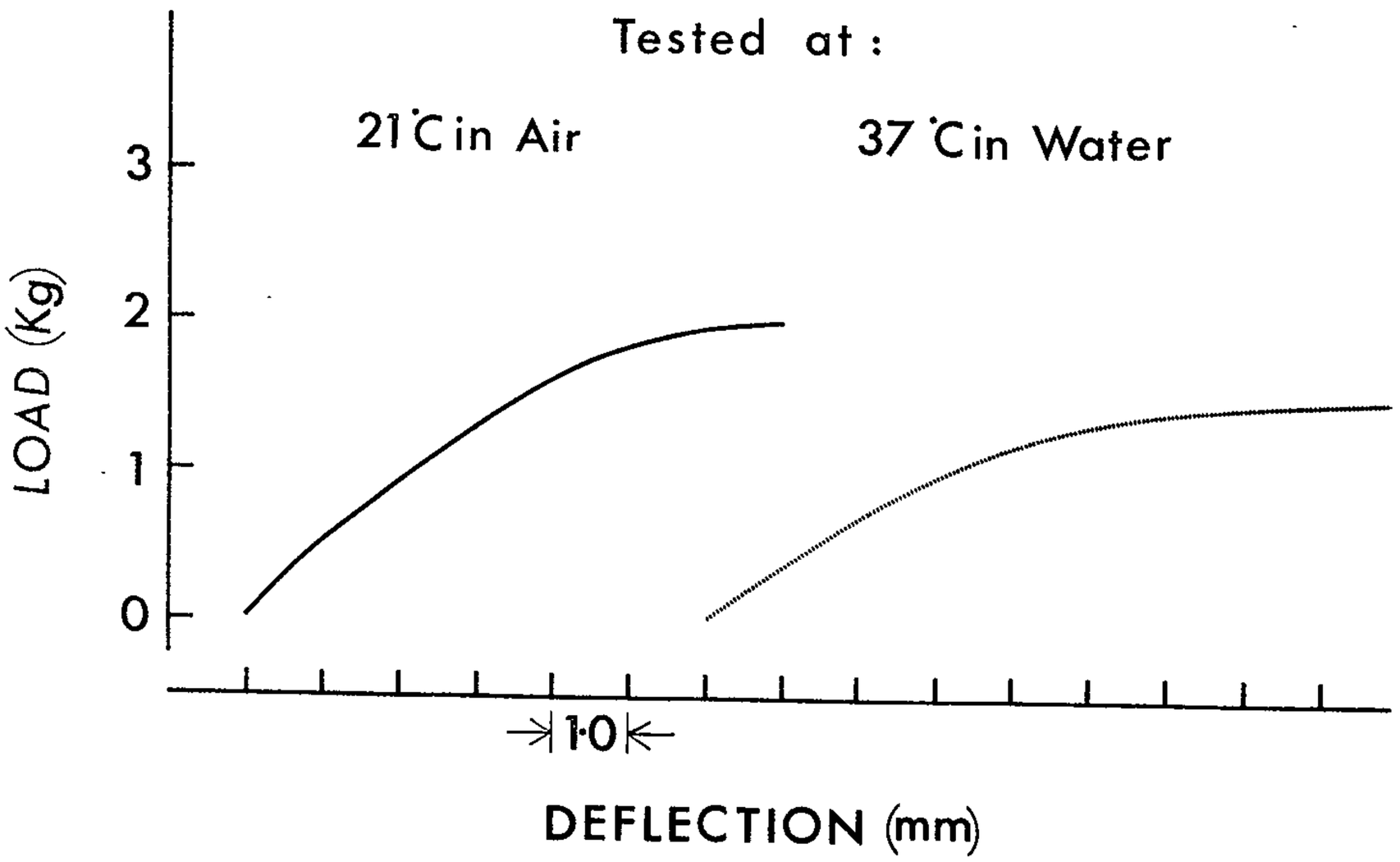


Figure 3-3

Load-deflection graph for Bayer.

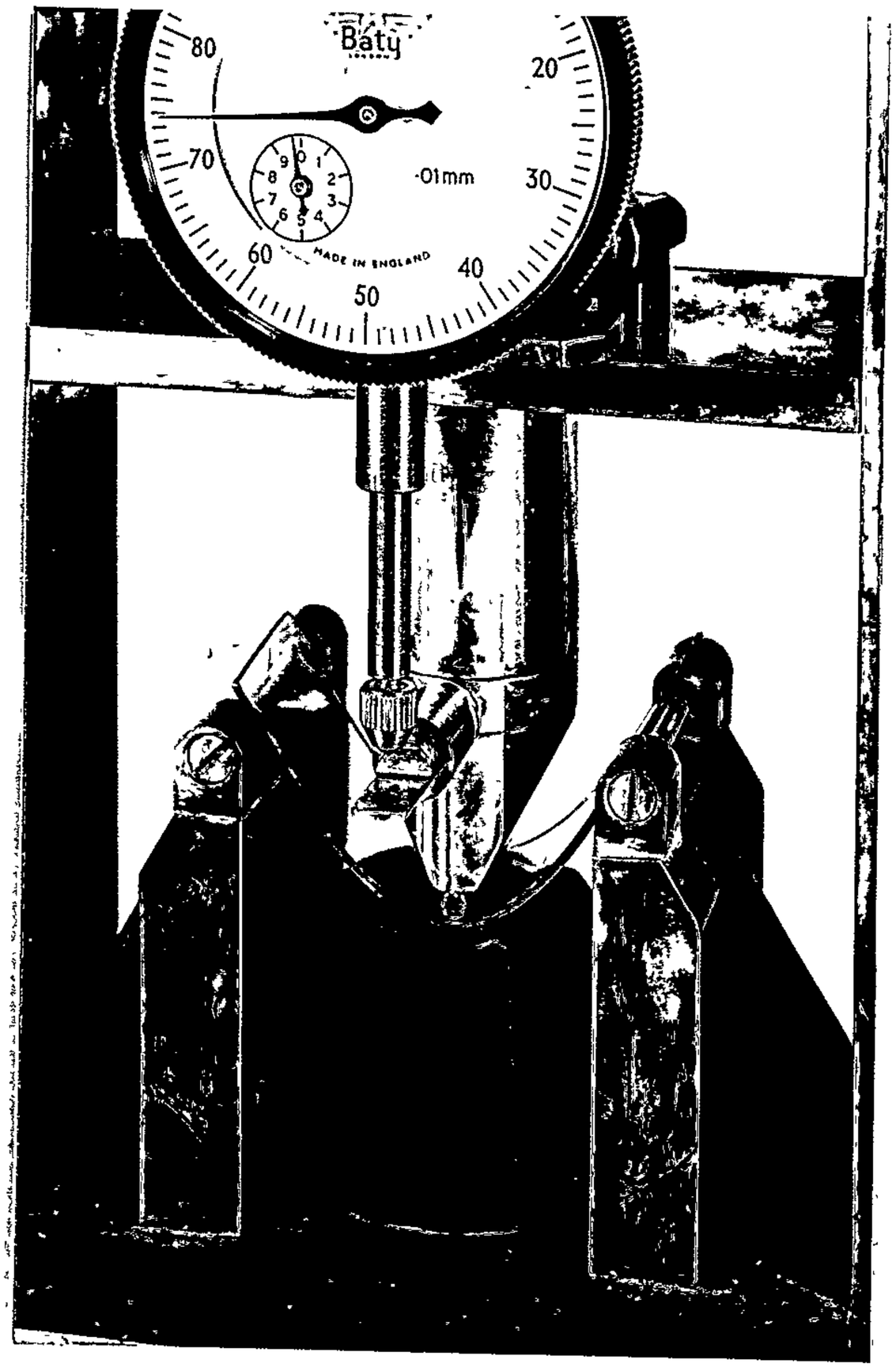


Figure 3-4

A Keba-Plast specimen deflecting through the range of the testing machine.

3.5.2. Flow:

The results of flow tests at 21°C in air and at 37°C in water are shown in Table 3-3. At least two tests were carried out for each material and the difference between tests under the same conditions was no greater than ± 0.01 per cent.

TABLE 3-3.

FLOW

Material	Percentage Flow at:	
	21°C in air	37°C in water
Keba-Plast	0.0	< 0.1
Heko-Werk	0.0	0.0
Bayer	0.0	< 0.1

3.5.3. Dimensional stability:

The results of the tests for dimensional stability are presented in Table 3-4. At least ten tests were carried out for each material under each set of conditions, and the means and standard deviations are listed.

TABLE 3-4.

DIMENSIONAL STABILITY

Material	Warpage (mm)	
	(2 hours at 37°C)	(3 days at 37°C)
Keba-Plast	0.09 ± 0.02	0.10 ± 0.02
Heko-Werk	0.27 ± 0.04	0.94 ± 0.06
Bayer	0.14 ± 0.02	0.16 ± 0.02

3.5.4. Reproduction of surface detail:

The results of these tests are shown in Table 3-5.

TABLE 3-5.

REPRODUCTION OF SURFACE DETAIL

Material	Result of test
Keba-Plast	Failed
Heko-Werk	Failed
Bayer	Failed

3.6. DISCUSSION.

3.6.1. Transverse strength and rigidity:

It can be seen from the graphs in Figures 3-1 to 3-3 that the thermo-softening synthetic resin materials show plastic deformation whether tested in air at 21 ± 1°C or under water at 37 ± 1°C; this is indicated by non-linearity of the load-deflection curves.

Repeated tests on any given material, under the same conditions, gave results with good reproducibility; no variation was observed either in transverse strength or in rigidity.

Two of the materials, Bayer and Heko-Werk, showed a reduction both in transverse strength and rigidity when tests were made in water at 37°C instead of in air at 21°C. However, this was not observed in the case of Keba-Plast, which showed the same strength and rigidity under both sets of test conditions.

When the results of tests on the different materials are compared, it can be seen that both fracture load and stiffness varied. This could be expected from their differing composition, and also from the fact that the blanks of Bayer material were thicker than those of the other two.

It is interesting to note that Keba-Plast specimens

did not fracture in the test; instead, all specimens deflected through the whole range of travel of the testing machine. This material showed the greatest flexibility of the three as well as the highest strength. This is particularly marked in the case of tests in water at 37°C.

Bayer specimens were the most rigid, and Heko-Werk specimens the weakest, both when tested in air at 21°C and in water at 37°C.

3.6.2. Flow:

Flow tests were carried out at 21 and 37°C to determine whether these materials were likely to undergo plastic flow at room or mouth temperature. It can be seen from Table 3-3 that all the materials showed a flow of less than 0.1 per cent. It would be difficult to carry out flow tests at the softening temperatures of these materials (160°C for Keba-Plast and 180°C for Heko-Werk and Bayer), and these were not attempted.

3.6.3. Dimensional stability:

Palatal warpage for Keba-Plast and Bayer baseplates after conditioning in water at 37°C for two hours, was of the order of 0.1 mm, and this did not increase significantly after three days at 37°C. This suggests that when these baseplates are heated in water at 37°C, almost all stress

relief occurs within the two hour period immediately after manipulation.

Heko-Werk baseplates showed warpage of about 0.3 mm when conditioned for two hours in water at 37°C, and warpage of about 0.9 mm after three days under the same conditions. This indicates that stress relief was still taking place over this period. Thus it would appear that warpage would continue to occur over a long period when baseplates of this material are stored in air at room temperature.

3.6.4. Reproduction of surface detail:

It can be seen in Table 3-4 that none of these materials passed the reproduction of surface detail test. It has already been mentioned in Section 3.2 (page 81), that they also failed even when test conditions were made more favourable. In practical use, all of these materials can be expected to show poor reproduction of detail after adaptation to a cast.

CHAPTER 4

COLD-CURED ACRYLIC RESIN MATERIALS.

4.1. INTRODUCTION.

The three materials tested are listed in Table 1-1 (page 4), together with the names of their manufacturers. All except Traybase were supplied with volumetric measures for the powder and liquid. With Trayresin and Tray Plastic, the proportions by volume of powder and liquid are given also. Some instructions accompanied all materials, but these were always inadequate. The instructions described the manipulation of the materials while in the dough stage, but did not give any indication of doughing time, working time or hardening time for any material.

Traybase and Trayresin were also provided with formers for shaping the dough into blanks, from which trays or baseplates could be moulded.

4.1.1. Preliminary tests:

Because of this lack of necessary information, preliminary experiments were necessary, to develop standardised methods of specimen preparation. These preliminary experiments involved the study of a group of properties which were not encountered with the other two types of materials; these were the properties concerned with the manipulation of

the unpolymerised powder-liquid mixtures. The properties investigated were doughing time, working time and hardening time.

The results of these tests showed the time after mixing when moulding of each material could begin, the time available for moulding, and the time when specimens would be strong enough to separate from a mould.

Moulds were used to shape the dough into specimens for strength, flow and dimensional stability tests, and these moulds are described in Section 4.2.

4.1.2. Doughing time:

With each material, the powder and liquid were proportioned according to the manufacturer's instructions, and were allowed to dough in a glass mixing jar, maintained at 21 ± 1°C. The American, British and Australian Specifications for denture base resin[12,13,14] state that the material is ready for packing when it separates cleanly from the walls of the mixing jar. The time interval from the start of mixing the monomer and polymer, until the resin no longer adhered to the sides of the mixing jar, was determined for each material, and is recorded in Table 4-1 as the doughing time.

4.1.3. Working time:

With the acrylic resin materials, the packing properties test, as defined in the specifications[12,13,14], is an assessment of the plasticity of the material - its ability to reproduce surface detail. Since the specifications[12,13,14] state that the packing properties test shall be started five minutes after the dough stage has been reached, this ensures a working time of at least five minutes.

A subjective appraisal of the working time of these materials was first carried out, by testing the powder-liquid mixture with the fingers every 30 seconds after it had reached the dough stage, until the onset of the rubbery stage of polymerisation was apparent. The rubbery period was very short and all the materials hardened almost immediately after they left the dough stage. These results are shown in Table 4-1.

For the objective assessment of working time, use was made of the test previously employed for determining the reproduction of surface detail of shellac materials (Section 2.4.4 page 50). However, in these tests on acrylic resin dough, the interposition of polyurethane foam was unnecessary. The resins were mixed according to the manufacturer's instructions, and after the doughing time was reached, approximately 6 to 10 gm were placed on the perforated brass

die. A glass plate was placed on the resin, separated from it by a sheet of 0.001 inch thick polyethylene film, and a weight of 0.5 kg placed on the plate for one minute. After this time, the weight was removed and the resin specimen allowed to remain on the brass die until the hardening time was reached, when the specimen could be removed from the die and examined. The test was carried out at one minute intervals from the onset of the dough stage, and if all the holes in the die were reproduced by the material, it was regarded as having passed the test and being adequately plastic at that stage. It was found that this test gave similar working times to those previously determined subjectively. The working times determined for the four materials are listed in Table 4-1.

It was thought that plasticity and working time should also be assessed according to the packing properties test, as defined in the acrylic resin specifications. Each material was mixed according to the manufacturer's instructions and five minutes after the dough stage was reached, 6 to 10 gm of resin was placed on the brass die. A glass plate was placed on the specimen, separated from it by a sheet of 0.001 inch polyethylene film, and a weight of 5 kg placed on the glass plate for 10 minutes. In order to pass the test, the resin must have intruded into at least two holes of the die, for a depth of not less than 0.5 mm. Results of these tests are shown in Table 4-2.

4.1.4. Hardening time:

The subjective assessments of working time described in the previous section showed that the hardening time of the resin, taken from the time of mixing, should be given, at least approximately, by the sum of the doughing time and the working time. To confirm this it was thought that hardening time could be assessed directly by means of a Gillmore needle; at the stage in polymerisation represented by the Gillmore initial set, the resin should not distort when subjected to small stresses. Thus a specimen could be carefully removed from its mould, or a baseplate from its cast, without distortion.

It was also considered interesting to investigate a possible correlation between the hardening time and the time at which the peak of the temperature rise occurred in the polymerising resin. Skinner and Phillips[26] mention this fact with reference to the cold-cured acrylic resins for tooth restorations: "It should be noted that the peak temperature is of practical importance only to the extent that it indicates the proper time at which the matrix strip can be removed". This implies that the surface of the resin is sufficiently hard at this stage to withstand any small stresses without distortion or fracture. This fact should be true of the cold-cured acrylic resin baseplate materials also. Therefore measurements of temperature evolution were made simultaneously with the Gillmore tests by means of a 30 gauge chromel-alumel

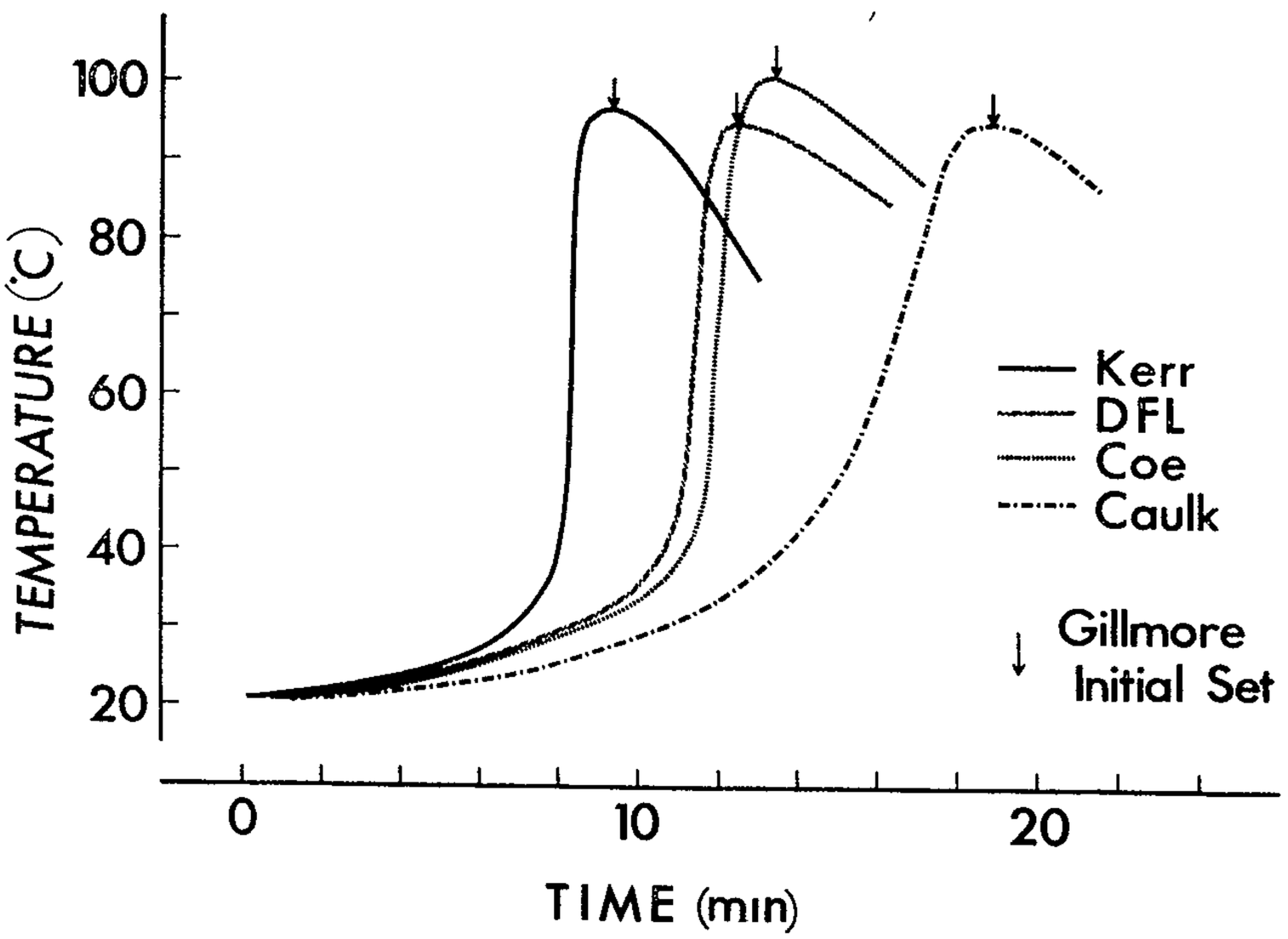
DENTISTRY LIBRARY SYDNEY UNIVERSITY
101

thermocouple, positioned in the centre of the specimen and connected to a potentiometric recorder, as described in Section 2.2.2 (page 17).

Immediately after mixing, the resin was placed in a cylindrical mould, 2 cm in diameter and 2 cm high, with the hot junction of the thermocouple positioned in the centre. Tests were made on the surface of the specimen every 30 seconds with the initial set Gillmore needle, and the times at which the needle first failed to make a complete indentation are listed in Table 4-1.

The peak of the temperature rise occurred at the same time as the Gillmore "initial set". This correlation was valid for all four materials. The temperature rise was quite rapid, but once the peak was reached, the temperature fell slowly. This was contrary to the results obtained by other workers[27,28], who found a rapid decrease in temperature once the peak of the exothermic reaction was reached. However, the temperature fall is greatly affected by the bulk of resin, and since the thermocouple was positioned in the centre of a fairly large mass of resin, the fall in temperature at the centre would be gradual.

Times at which peak temperature was reached are shown in Table 4-1; temperature evolution curves are illustrated in Figure 4-1.



Temp. Adiabatic

Figure 4-1

4.1.5. Application:

A study of these results allowed the development of standardised methods for the manipulation of these materials; the dough was packed into the mould after a fixed time interval from the start of mixing, given by the doughing time of the particular material being used, and could be removed from the mould without distortion after its hardening time was reached. As mentioned in Section 4.1.1, moulds were used to prepare specimens from the dough, for flow, transverse strength and dimensional stability tests. These moulds are described in detail in the appropriate parts of Section 4.2.

TABLE 4-1.

Material Tested	Doughing Time (minutes after mixing)	Working Time (minutes after reaching dough stage)	Hardening Time		Peak Temp. (°C)
			Peak of Temp. Rise (minutes after mixing)	Gillmore Initial Set (minutes after mixing)	
Trayresin	9	10	19	19	96
Formatray	7.5	2	9.5	9.5	95
Traybase	7.5	6	13.5	13.5	97
Tray Plastic	6.5	6	12.5	12.5	102

TABLE 4-2.

SPECIFICATION TEST FOR PACKING PROPERTIES

Material	Result
Trayresin	X
Tray Plastic	X
Traybase	.
Formatray	.

A cross (X) indicates that the material passed the test.

4.2. DEVELOPMENT OF TESTING METHODS.

4.2.1. Transverse strength and rigidity:

So that a valid comparison of transverse strength and rigidity could be made, specimens were prepared of similar size to those made from the shellac and the thermo-softening synthetic resin baseplate blanks. Since the cold-cured acrylic resin baseplate materials are not supplied as preformed blanks, a mould was necessary to standardise specimen preparation from the resin dough. The mould was 2 mm deep, so that specimens would be approximately 2 mm thick. This depth was chosen since with Trayresin and Traybase, a former is supplied and the mean thickness of a baseplate prepared using these formers is 2 mm. The mould was 2.5 cm wide and 7.0 cm long; length was not critical, but a specimen must be at least 6.0 cm long in order to span the supports of the testing machine. The mould (illustrated in Figure 4-1), was open at one end so that the material was not confined during polymerisation. Manufacturers recommend moulding the resin dough on to a cast with the fingers, in which case the material would not be confined, even if a mould former were used initially to obtain an approximate shape. Thus, the mould was designed to allow manipulation of the resin according to the manufacturer's instructions. The base of the mould was made from P.T.F.E., 0.25 inch thick, to prevent adhesion of the dough. The sides of the mould were made of brass and were coated with a thin film of silicone release agent (Releasil 7, supplied by Midland Silicones Ltd.).

During preparation of specimens, the material was mixed as suggested by the manufacturer and placed in the mould once the doughing time was reached. Then a brass roller was used to adapt the resin within the mould (Figures 4-2, 4-3). This method of preparation simulated one way of using the materials in practice, since the manufacturer of Trayresin suggests rolling the dough flat and then adapting to the cast with the fingers.

Specimens so formed were tested after one hour, after 24 hours' storage in air and in water, and after 72 hours' stored in air and in water; tests were carried out at 21°C in air and at 37°C in water. The material was stored in air at 21 ± 1°C and in water at 21 ± 1°C, to determine whether the storage in water resulted in a significant reduction in strength and rigidity. It has been stated[29,30] that storing the resin in water results in water sorption and a loss of free monomer by leaching; the net result is an increase in plasticity of the resin. The storage times were selected to determine the most suitable period of storing the polymerised material before use, and also under what conditions the materials should be stored.

It was found that specimens prepared in the mould described, varied in thickness from 2.1 mm to 2.6 mm. Different specimens of the same material varied in thickness, as well as specimens prepared from different materials. It was extremely

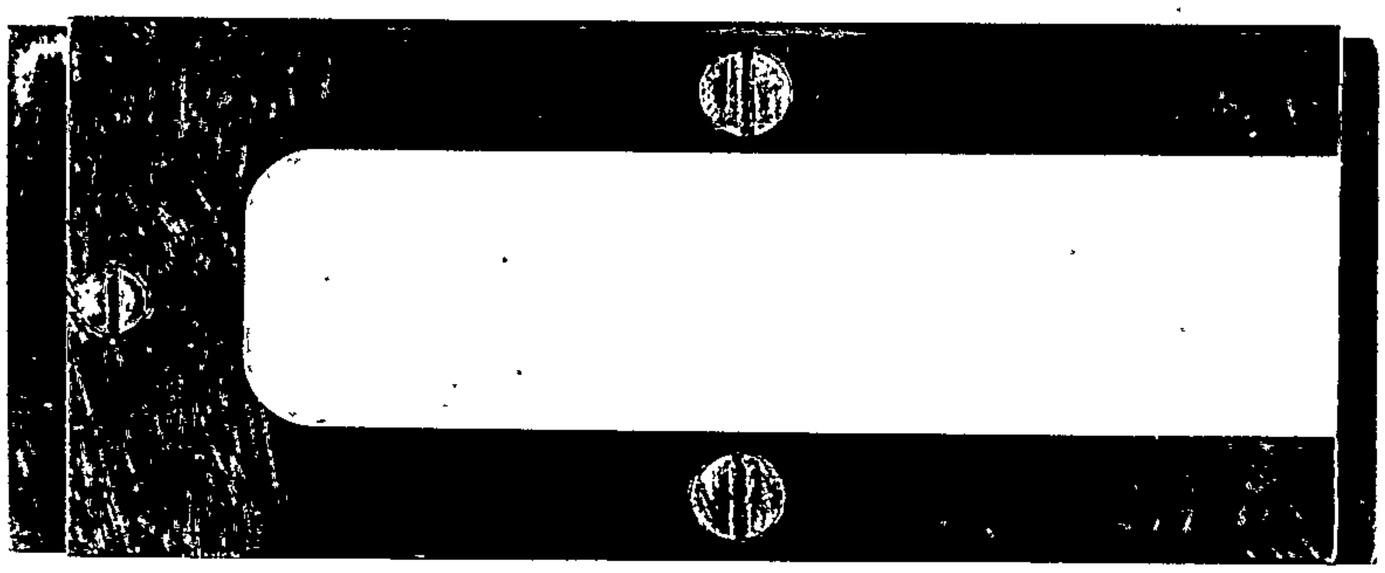


Figure 4-2



Figure 4-3

Acrylic resin dough being adapted into the mould.

difficult to prepare specimens of uniform thickness with Traybase, since the powder contained a proportion of very large polymer pearls, which prevented the formation of a uniformly thin flash on the sides of the mould. With Formatray, the short working time prevented complete adaptation within the mould, before the resin became rubbery.

The variation in thickness of the specimens, therefore, prevented a comparison of the strengths of the cold-cured acrylic resin baseplate materials themselves. Instead, it was valid only to compare the strengths of baseplates prepared from these materials. It would appear that if it were not possible to obtain transverse strength specimens of a uniform thickness using a mould and roller, then baseplates prepared on a cast would show a greater variation in thickness, even if a former were used initially.

It was thus decided to prepare specimens in accordance with a specification, as well, so that a comparison of the strength and rigidity of the individual resin materials could be made.

The American[12], British[13] and Australian[14] specifications require the preparation of transverse strength specimens by curing the resin under pressure in a gypsum mould. These procedures are designed for denture base resins and do not reproduce the use of the cold-cured acrylic resin baseplate materials in practice. For this reason specimen preparation was

altered.

In practice, the manufacturers of these materials suggest moulding the material on to a cast when the resin has reached the dough stage, and subsequent polymerisation takes place in air at room temperature. In specimen preparation for specification tests for transverse strength and rigidity, a mould similar to the previous one could have been used. However, so that a number of specimens could be prepared from one mix of resin, another mould was designed (Figure 4-4). At least five specimens could be prepared at one time, and this allowed at least five tests on one material, under one set of conditions, to be carried out on specimens from the same mix of resin.

The mould consisted of two sheets (3 in. x 4 in.) of Glacier D.U. strip (P.T.F.E. impregnated bearing material). One sheet was bolted to a strip of brass and the bolt heads were milled so as to project 2.6 mm above the base; these thus acted as spacers for the other sheet of bearing material, which formed the top of the mould. The sides of the mould were open so that the resin was not confined during polymerisation. This mould produced a flat sheet of resin 2.6 mm thick, which was cut into strips with a hand saw. Strips were supported in metal jigs (Figure 4-5) as described in the draft revision of the British specification for resins[31], and were reduced in

size with wet silicon carbide abrasive paper until they were 2.5 mm thick, 10 mm wide and approximately 6.0 cm long.

It was of interest to determine whether strength and rigidity were affected significantly, by allowing the resin dough to polymerise under pressure. One material was selected, and further specimens were prepared according to the proposed revision of B.S. 2847 for denture base resins. This requires the preparation of separate moulds for each specimen. Brass plates are embedded in stone in the lower half of a dental flask; once the stone has set the brass plates are removed and the counter half of the mould formed. Specimens prepared in these moulds are larger than specification size, since the brass plates are oversized and specimens are reduced to specification dimensions using jigs (Figure 4-5) and silicon carbide abrasive paper. All the specimens prepared to specification size were subjected to three point loading which was carried out according to the incremental pattern defined in the standard specifications[12,13,14] for acrylic resins. The specimens prepared for comparison with the previous two groups of materials were loaded continuously at 1500 gm/minute according to the baseplate specification[15].

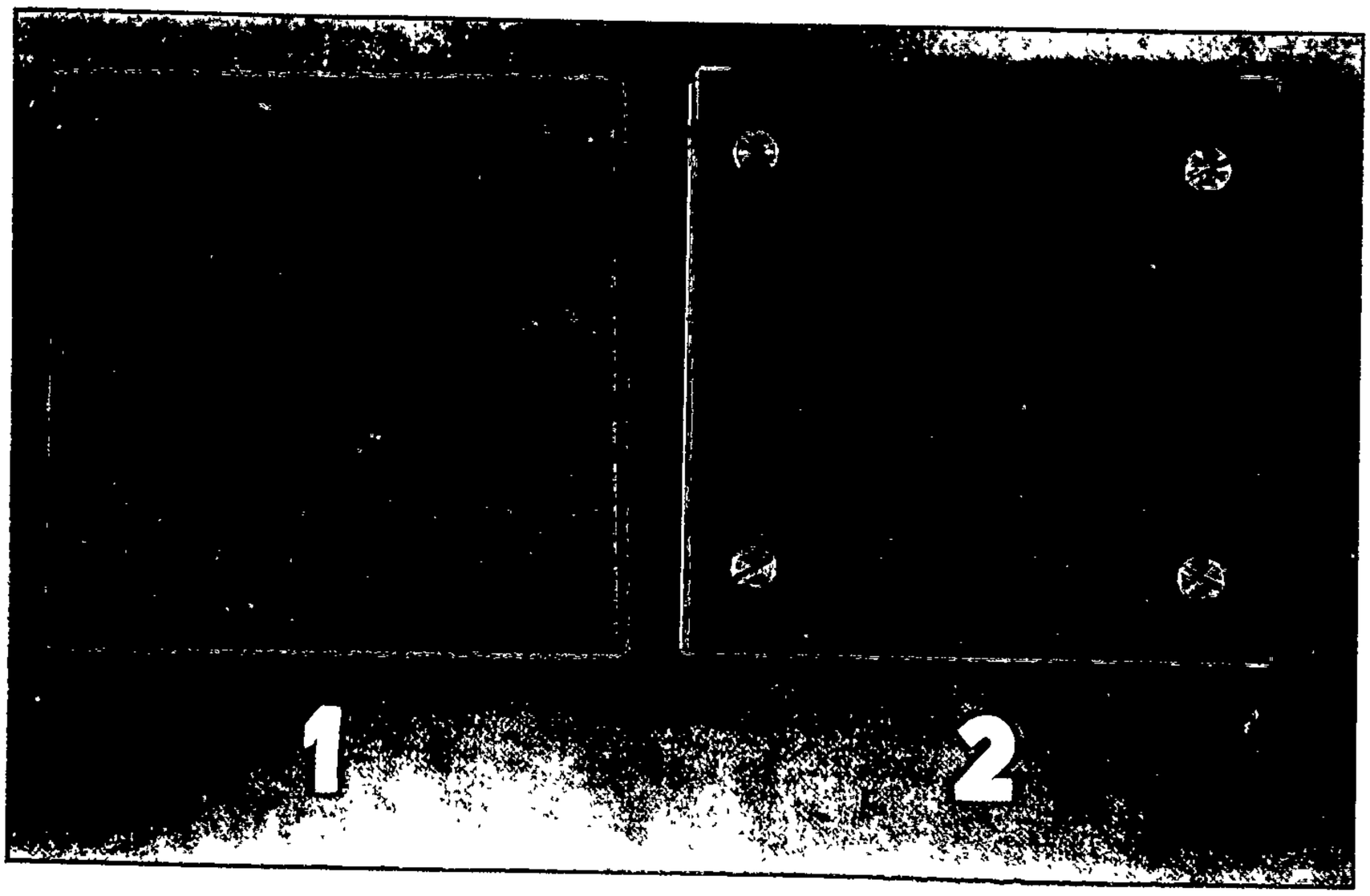


Figure 4-4

1. Top; 2. Base of mould.

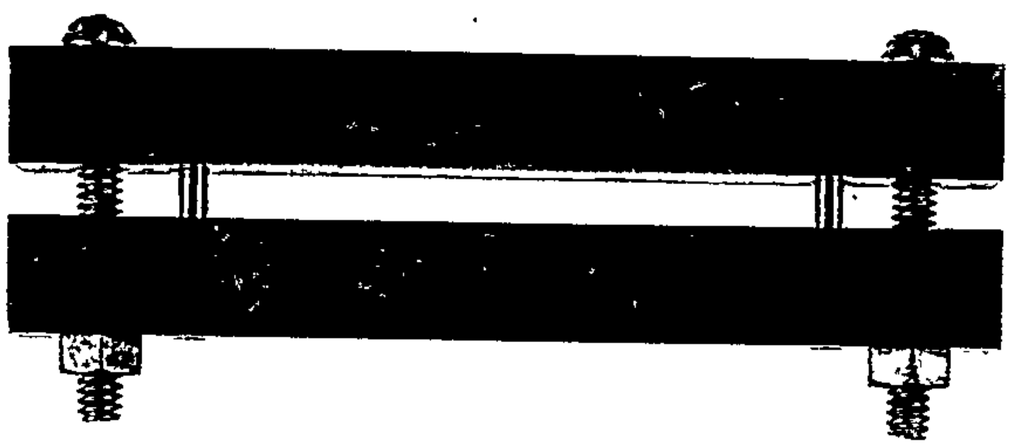


Figure 4-5

4.2.2. Flow:

During transverse strength tests with the cold-cured acrylic resin materials, and most especially with strength tests carried out one hour after mixing the monomer and polymer, it was found that there was some permanent deformation of the specimens following fracture. Trayresin retained its plasticity for a longer period than the other materials; in fact when specimens were subjected to the three point loading of the transverse test, in water at 37°C and one hour after mixing, fracture did not occur. Instead, the material deflected under load for the full range of the dial gauge, and when the load was removed, the specimen retained its deformed shape (Figure 4-6).

The other materials were less plastic and it was decided to carry out flow tests at 21°C and 37°C to determine the relative degree of plastic deformatiom of the four acrylic resin materials.

Flow specimens were prepared and tested after one hour, after 24 hours and 72 hours from the beginning of mixing. Some specimens to be tested after 24 hours and 72 hours were stored in air and others were stored in water, since it was thought that storage in water could render the specimens more plastic than those stored in air.

It would be difficult to carry out flow tests at temperatures above the softening temperature of the resin;

the results of such tests would be of no practical significance and these were not attempted.

4.2.3. Dimensional stability:

The test used to assess the dimensional stability after moulding for the previous two groups of materials, was suitable for the cold-cured acrylic resin materials also. The stone die was modified to incorporate three stops (Figure 4-7), so that the cast and counterdie were separated by a uniform distance of 2.0 mm. Thus all acrylic resin baseplates prepared on the cast and counterdie were of uniform thickness. The cast and counterdie were coated with an alginate separating film (Acr-Film, supplied by Engelhard Industries Pty. Ltd.), to prevent the resin from adhering to the stone during the forming of the baseplates.

The cold-cured acrylic resin baseplate materials, unlike the preceding two groups of materials, demonstrated continued polymerisation; this fact was indicated by an increase in strength as storage time increased. Warpage was measured after two hours in a water bath at 37°C, to simulate the possible dimensional change which would occur when a baseplate was used in the mouth, and also following storage at 37°C for three days. This latter period would indicate whether the continued polymerisation of the resin results in significant warpage. In practice, baseplates would be stored in air at 21°C rather than



Figure 4-6

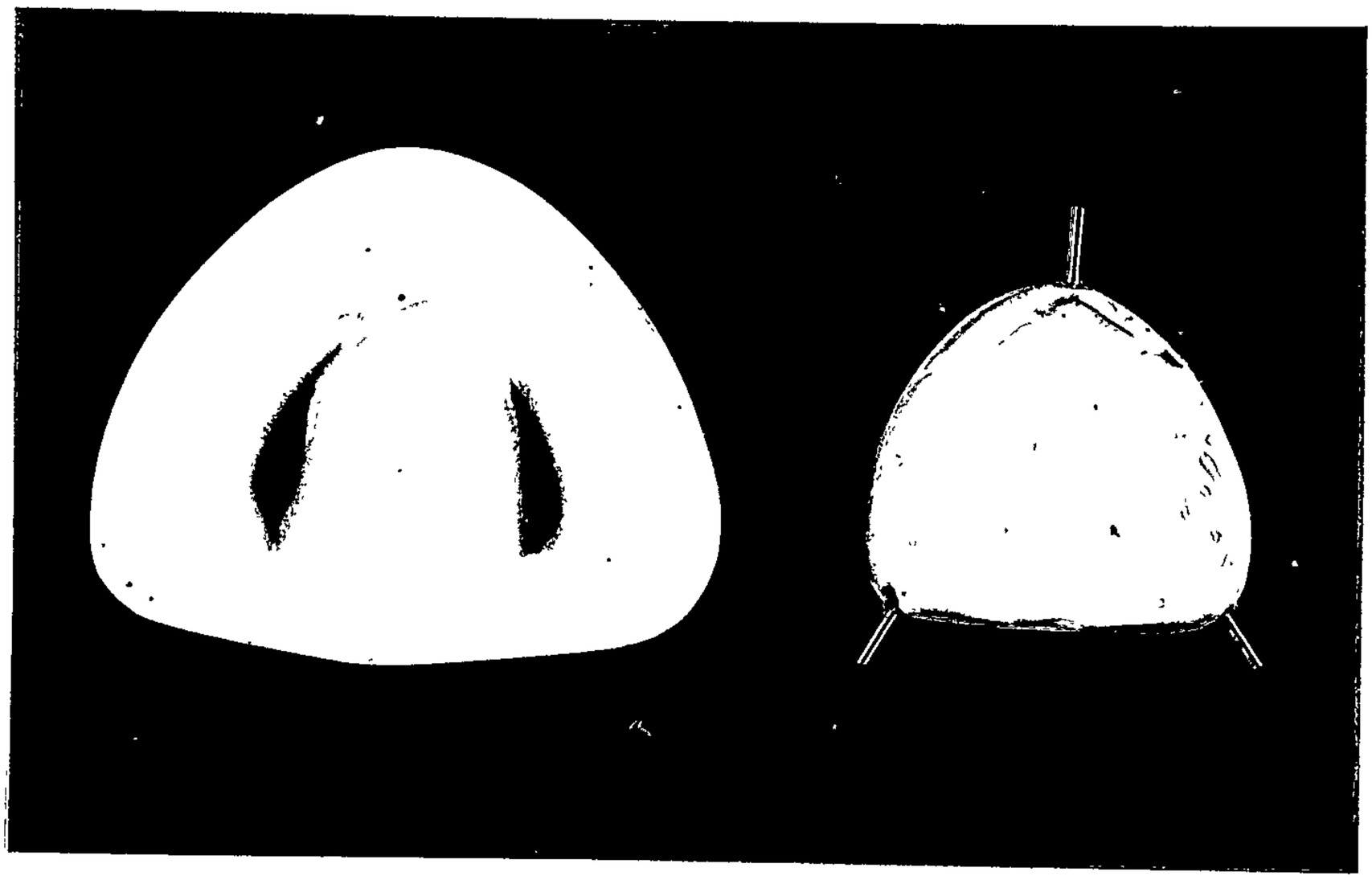


Figure 4-7

in water at 37°C, but storage in water at 37°C would merely accelerate the warpage that would normally occur at 21°C in air.

4.2.4. Reproduction of surface detail:

The qualitative reproduction of surface detail test was carried out while making the preliminary tests of working time of the resins, described in Section 4.1.3. The packing properties test as defined in the acrylic resin specifications[12,13,14] was also carried out during the preliminary tests on the materials.

4.3. APPARATUS.

4.3.1. Transverse strength and rigidity:

The mould used for preparing specimens, for strength tests in accordance with the U.S. Federal Specification for baseplates[15], is illustrated in Figure 4-2. It consisted of a length of 0.25 inch brass as the base, with a strip of 0.25 inch P.T.F.E. of similar dimensions attached to it; the sides of the mould were provided by a 2 mm thick section of brass overlying the P.T.F.E. sheet and screwed to the base. The 2 mm thick brass sheet was U-shaped where the internal dimensions of 2.5 cm wide and 7.0 cm long formed the mould, so that specimens were 2.5 cm wide and approximately 7.0 cm

long. The open end of the mould allowed unconfined polymerisation of the resin. The screws which held together the parts of the mould were countersunk, so that a brass roller could be used along the top of the mould, to force the resin dough into the mould during specimen preparation.

The mould used for preparing specimens to be tested according to the acrylic resin specifications[12,13,14] is illustrated in Figure 4-4, and is described in Section 4.2.1. Use of this mould produced a sheet of polymerised resin approximately 7 cm x 7 cm, and 2.6 mm thick. A hand saw was used to cut the flat sheet of polymerised resin into strips. These were oversized and jigs (Figure 4-5) were used to support the strips while they were reduced to the required specification size with 220A silicon carbide abrasive paper.

Jig 1 was used to reduce the specimens to the required width. It consisted of two hardened steel bars of square cross section, 80 mm long and 10 mm wide; bolts were placed 10 mm from each end and the distance between the bolts was 60 mm, so that specimens were adjusted to the required length before being placed on the jig. Guide rods housed in each end of one bar allowed the second bar to be positioned accurately before bolting the two bars together. One, two or three specimens could be clamped in the jig at any one time and were reduced in width with 220A silicon carbide abrasive

paper until each side of the specimen was exactly level with the sides of the jig.

Jig 2 was used for reduction in depth of the specimens. Two hardened steel bars, 60 mm long and 10 mm square, were screwed on to a brass bar which was also 60 mm long and 10 mm square. The steel bars projected 2.5 mm above one face of the brass bar, leaving a recess 10 mm wide, 2.5 mm deep and 60 mm long. Brass plates were attached to the ends of the bars so that the specimen was completely confined within the recess in the jig. The face of the specimen was reduced in thickness with 220A silicon carbide abrasive paper until it was level with each hardened steel bar, after which time the thickness of the specimen was 2.5 mm.

The apparatus used for strength and rigidity tests on the acrylic resin specimens was the same as that used for similar tests on the shellac baseplate materials. The apparatus is illustrated in Figure 2-12. The loading mechanism was such that specimens prepared for comparison with the shellac materials could be loaded according to the U.S. Federal Specification for baseplates[15] (1500 gm/minute), whilst the specimens prepared according to the acrylic resin specifications[12,13,14], could be loaded according to the incremental pattern defined in these specifications (500 gm added during the last 30 seconds of each minute).

4.3.2. Flow:

Flow specimens of cold-cured acrylic resin material were prepared using the same mould as was used for preparing the shellac flow specimens (Figure 2-6). The testing machine was also used for flow tests on the shellac materials previously and is illustrated in Figure 2-5.

4.3.3. Dimensional stability:

The mould used to assess warpage of the acrylic resin materials was the same as that used for the two previous groups of materials, except that for the acrylic resin tests the cast was modified to incorporate three stops. These maintained a uniform space within the mould and were essential for producing a baseplate of uniform thickness, due to the initial plasticity of the resin materials. The stops were placed in three positions equidistant around the base of the cast (Figures 4-7, 4-8).

The dial gauge comparator used for measuring warpage was the one used for tests on the shellac materials and is illustrated in Figure 2-9.

4.3.4. Reproduction of surface detail:

The die used for reproduction of surface detail tests on acrylic resin was the one used for similar tests with the shellac materials. When this test was carried out with the

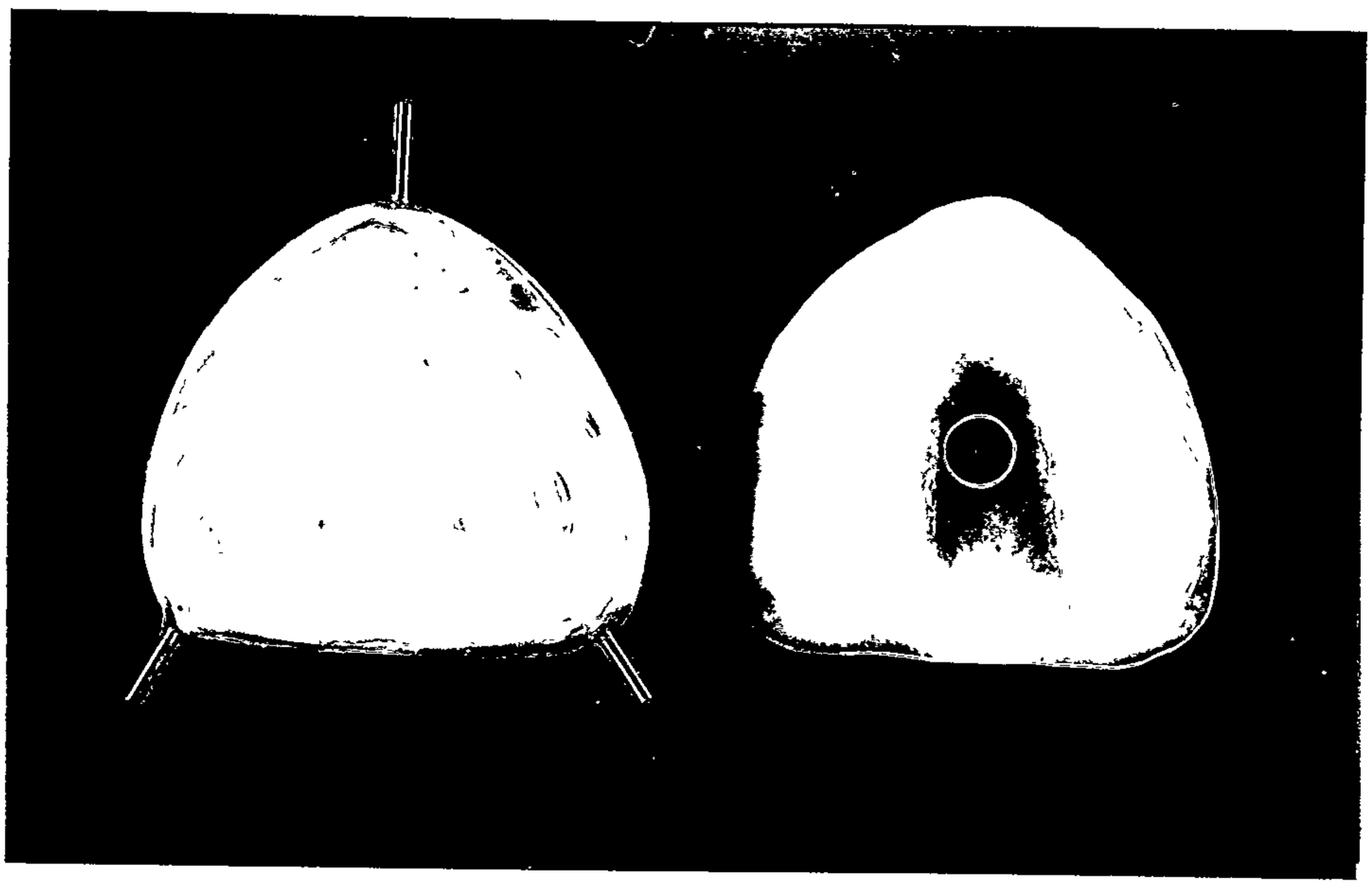


Figure 4-8

Cast and baseplate.

acrylic resin materials it was not necessary to interpose the sheet of polyurethane foam between the material and the loaded glass plate, due to the plasticity of the dough. For the packing properties test as defined in the specifications[12,13,14] which was carried out also, a weight of 5 kg was applied, and a 0.001 inch polyethylene film was placed between the dough and the loaded glass plate to prevent the dough from adhering to the plate.

4.4. EXPERIMENTAL METHOD.

4.4.1. Transverse strength and rigidity:

(a) For tests which could be compared with the tests on other baseplate materials, specimens were prepared using the mould illustrated in Figure 4-2. The powder and liquid were proportioned according to the manufacturer's instructions, and mixed in a glass container which was maintained at 21 ± 1°C before use. When the doughing time had been reached, the resin was removed from the jar and adapted into the mould with the aid of a brass roller (Figure 4-3). When the hardening time had been reached, the specimen was removed from the mould; the thin flash was broken from the sides of the specimen and any minor adjustments to width carried out with 220A silicon carbide abrasive paper.

The specimens were subjected to the transverse

strength test after one hour, after 24 hours and after 72 hours from the start of mixing the resin. Tests were carried out in air at 21°C and in water at 37°C, and the specimens tested after 24 hours and 72 hours were stored in air at 21 ± 1°C or in water at 21 ± 1°C for these periods.

After the appropriate storage period, the specimen was positioned across the supports of the testing machine and loading was commenced from an initial zero load, at the rate of 1500 gm/minute. Readings of deflection were taken every 10 seconds until fracture occurred, at which time the loading mechanism was immediately stopped and the fracture load noted.

(b) For tests based on the acrylic resin specifications[12,13,14], specimens were prepared using the mould illustrated in Figure 4-4. The resin was mixed according to the manufacturer's instructions and was removed from the mixing jar when the doughing time was reached. The resin dough was placed between the two sheets of bearing material and a load of 10 kg applied to the top sheet. The edges of the mould were open so as not to confine the polymerising resin, and the weight of 10 kg was used merely to maintain the top bearing sheet firmly on the stops.

When the hardening time had been reached, the weight was removed and the mould separated. A hand saw was used to cut the sheet of resin into strips which were approximately

12 mm wide and 65 mm long. From this point specimen preparation followed the method laid down in the draft revision of B.S. 2847. The jigs illustrated in Figure 4-5 were used to confine the specimens while further adjustments to size were made with 220A silicon carbide abrasive paper, until the specimens were 2.5 ± 0.03 mm thick, 10.0 ± 0.03 mm wide and 60-65 mm long. Finished specimens were stored in water at 37°C for one week before testing at 37°C in water.

Following storage, the specimens were positioned across the supports of the testing machine and an initial load of 1500 gm applied. The load was increased at the rate of 500 gm during the last 30 seconds of every minute. Readings of deflection were taken every minute immediately before adding a load increment, until fracture of the specimen occurred. The data obtained allowed load-deflection curves to be drawn for all tests.

4.4.2. Flow:

Specimen preparation was by the method described in Section 2.4.2 (page 47). The mould illustrated in Figure 4-2 was used, and the sides were covered with a thin layer of silicone release agent. The acrylic resin was forced into the mould once the doughing time for the particular resin was reached. Once the hardening time was reached the specimens were removed from the mould, and minor alterations to the

smoothness of the flat face of each specimen were then made as before (Section 2.4). Specimens to be tested after 24 hours and 72 hours were stored in air at 21 ± 1°C or in water at 21 ± 1°C.

Flow tests were made by the method described in Section 2.4.2 (page 47), except that the specimens were conditioned for 20 minutes in the water bath before beginning a test. Tests were made in air at 21 ± 1°C, and in water at 37 ± 1°C.

4.4.3. Dimensional stability:

The resin was manipulated according to the manufacturer's instructions. Once the doughing time was reached, the resin was removed from the mixing jar, and kneaded to form a flat sheet of resin which was placed on the cast, and forced on to the palatal section with finger pressure. Specimen preparation then followed the method described in Section 2.4.3 (page 49). The test for dimensional stability also followed the method described in Section 2.4.3.

However, once measurements had been made of the palatal warpage after two hours' immersion in water at 37 ± 1°C, a second series of tests was made as described in Section 3.4.3.

4.4.4. Reproduction of surface detail:

The tests carried out in Section 4.1 to assess the working time of the materials, also allow an assessment of reproduction of surface detail. The tests are described in detail in Section 4.1.

4.5. RESULTS.

4.5.1. Transverse strength and rigidity:

The results of the transverse tests for strength and rigidity are presented in the following tables. Tables 4-3, 4-4, 4-5 and 4-6 show the results of tests on specimens for comparison with similar tests with the two preceding groups of materials. The specimen thicknesses given represent the mean thickness of the specimens tested under any one set of storage conditions; each result is the mean of at least three tests.

Tables 4-7, 4-8, 4-9 and 4-10 show the results of tests carried out on specimens which were of specification[12,13,14] dimensions, in order to compare the relative strength and rigidity of the individual acrylic resin baseplate materials under investigation.

The results of all transverse tests are illustrated in Figures 4-9 to 4-32. Each figure shows all the results, after testing in air at 21°C and under water at 37°C, for one material under one set of storage conditions. In Figure 4-33,

one load-deflection curve is drawn to represent a series of tests under one set of conditions. In all cases the particular curve chosen was that of the actual test which most closely approximated the median of the series of tests.

TABLE 4-3.

TRANSVERSE STRENGTH & RIGIDITY.

Material: Trayresin

Test Conditions	Temp. (°C)	No. of Tests	Thickness of Specimen (mm)	Average Deflection (mm) at 1500 gm	at 2000 gm	at 2500 gm	maximum deflection	Fracture Load (kg)
1 Hour	21	4	2.2	1.6	2.4	3.3	10.8	4.6
	37	4	2.1	4.9	13.0	-	20.0	2.1 ✱
24 Hours stored in water	21	4	2.2	1.0	1.5	2.0	12.8	6.5
	37	4	2.1	1.2	1.9	2.6	20.0	5.0
24 Hours stored in air	21	4	2.3	1.0	1.5	2.1	8.0	6.5
	37	4	2.2	1.9	2.9	4.3	20.0	3.7
72 Hours stored in water	21	4	2.2	0.7	1.0	1.3	6.2	8.0
	37	4	2.1	1.2	1.8	2.6	17.0	4.6
72 Hours stored in air	21	4	2.3	0.7	1.0	1.3	10.0	8.5
	37	4	2.1	1.4	2.3	3.5	16.0	4.2

✱ The specimen did not fracture at this load, but deflected out of the range of the dial gauge.

TABLE 4-4.

TRANSVERSE STRENGTH & RIGIDITY.

Material: Tray Plastic

Test Conditions	Temp. (°C)	No. of Tests	Thickness of Specimen (mm)	Average Deflection (mm) at 1500 gm	at 2000 gm	at 2500 gm	maximum deflection	Fracture Load (kg)
1 Hour	21	4	2.3	1.1	1.4	1.8	3.6	4.5
	37	4	2.2	1.1	1.9	2.8	5.5	3.1
24 Hours stored in water	21	4	2.6	0.6	0.8	1.1	3.5	6.0
	37	4	2.5	0.7	1.1	1.5	5.0	5.0
24 Hours stored in air	21	4	2.5	0.6	0.8	1.1	3.1	5.5
	37	4	2.5	0.7	1.0	1.3	4.4	5.2
72 Hours stored in water	21	4	2.3	0.6	1.0	1.3	3.0	4.9
	37	4	2.2	1.0	1.6	2.3	4.5	3.4
72 Hours stored in air	21	4	2.2	0.7	1.0	1.4	4.1	4.8
	37	4	2.2	1.3	2.2	3.1	4.1	2.8

TABLE 4-5.

TRANSVERSE STRENGTH & RIGIDITY.

Material: Traybase

Test Conditions	Temp. (°C)	No. of Tests	Thickness of Specimen (mm)	Average Deflection (mm) at 1500 gm	at 2000 gm	at 2500 gm	maximum deflection	Fracture Load (kg)
1 Hour	21	4	2.1	0.9	1.3	1.8	12.0	7.5
	37	4	2.2	1.1	1.6	2.2	17.0	6.0
24 Hours stored in water	21	4	2.2	0.8	1.1	1.5	8.2	7.9
	37	4	2.1	1.0	1.5	2.1	12.4	6.2
24 Hours stored in air	21	4	2.2	0.6	0.9	1.2	7.4	9.2
	37	4	2.1	1.0	1.5	2.1	10.4	5.9
72 Hours stored in water	21	4	2.2	0.7	1.1	1.4	7.1	8.0
	37	4	2.2	0.8	1.2	1.7	10.1	7.2
72 Hours stored in air	21	4	2.2	0.7	1.0	1.3	6.2	8.4
	37	4	2.1	0.8	1.3	1.7	7.5	6.5

TABLE 4-6.

TRANSVERSE STRENGTH & RIGIDITY.

Material: Formatray

Test Conditions	Temp. (°C)	No. of Tests	Thickness of Specimen (mm)	Average Deflection (mm) at 1500 gm	at 2000 gm	at 2500 gm	maximum deflection	Fracture Load (kg)
1 Hour	21	5	2.4	0.7	1.0	1.4	5.1	5.2
	37	5	2.3	1.2	1.9	2.7	12.0	4.8
24 Hours stored in water	21	4	2.3	0.5	0.7	0.9	3.5	6.8
	37	4	2.3	0.6	0.9	1.3	7.0	6.5
24 Hours stored in air	21	4	2.3	0.5	0.7	0.9	3.1	6.8
	37	4	2.2	0.7	0.8	1.4	7.6	6.0
72 Hours stored in water	21	4	2.2	0.5	0.8	1.0	3.1	6.0
	37	4	2.1	0.7	1.1	1.5	8.3	6.1
72 Hours stored in air	21	4	2.3	0.4	0.6	0.8	4.1	9.0
	37	4	2.1	0.7	1.0	1.3	6.2	6.1

TABLE 4-7.

TRANSVERSE STRENGTH & RIGIDITY.

(Specification Test piece and loading rate.)

Material: Trayresin

Test Conditions	Temp. of Test (°C)	Thickness of Specimen (mm)	No. of Tests	Average Deflection (mm) 1500gm	2000gm	2500gm	3000gm	3500gm	4000gm	4500gm	5000gm	5500gm	Maximum Deflection	Fracture Load (kg)
1 Hour	21	2.5	4	0	0.7	1.5	2.5	4.1	6.8				7.2	4.0
	37		3	0	5.2								20.0 ⁂	2.5 ⁂
24 Hours stored in water at 21°C	21	2.5	2	0	0.5	1.0	1.5	2.1	2.8	3.7	5.0		6.0	5.4
	37		2	0	1.2	3.4	6.5						14.0	3.5
24 Hours stored in air at 21°C	21	2.5	2	0	0.5	0.9	1.4	2.0	2.6	3.4	4.4		6.0	5.5
	37		2	0	0.8	1.9	3.4	6.0					10.0	4.0
72 Hours stored in water at 21°C	21	2.5	2	0	0.5	1.0	1.6	2.3	3.3	4.5			6.4	5.0
	37		2	0	0.8	1.8	2.9	5.2	12.0				12.0	4.0
72 Hours stored in air at 21°C	21	2.5	2	0	0.5	1.0	1.5	2.1	2.9	3.8			5.1	5.2
	37		2	0	0.6	1.3	2.1	3.6	5.8				8.1	4.0
1 Week stored in water at 37°C	37	2.5	4	0	0.6	1.2	2.0	3.0	4.5				5.2	4.2

⁂ The specimen did not fracture at this load, but deflected out of range of the testing machine.

TABLE 4-8.

TRANSVERSE STRENGTH & RIGIDITY.

(Specification Test piece and loading rate.)

Material: Tray Plastic

Test Conditions	Temp. of Test (°C)	Thickness of Specimen (mm)	No. of Tests	Average Deflection (mm)									Maximum Deflection	Fracture Load (kg)
				1500gm	2000gm	2500gm	3000gm	3500gm	4000gm	4500gm	5000gm	5500gm		
1 Hour	21	2.5	3	0	1.3								2.0	2.2
	37		2	0	4.0								3.9	1.9
24 Hours stored in water at 21°C	21	2.5	2	0	0.7	1.8							2.0	2.5
	37		2	0	1.5								2.7	2.3
24 Hours stored in air at 21°C	21	2.5	2	0	0.6	1.3							2.0	3.0
	37		3	0	1.0	2.2							2.5	2.5
72 Hours stored in water at 21°C	21	2.5	2	0	0.7	1.5							1.6	2.4
	37		3	0	0.9	2.5							2.4	2.5
72 Hours stored in air at 21°C	21	2.5	5	0	0.5	1.2							1.5	2.6
	37		2	0	0.8	1.7							2.6	2.6
1 Week stored in water at 37°C	37	2.5	4	0	1.0	1.9							2.1	2.4

TABLE 4-9.

TRANSVERSE STRENGTH & RIGIDITY.

(Specification Test piece and loading rate.)

Material: Traybase

Test Conditions	Temp. of Test (°C)	Thickness of Specimen (mm)	No. of Tests	Average Deflection (mm) 1500gm	2000gm	2500gm	3000gm	3500gm	4000gm	4500gm	5000gm	5500gm	Maximum Deflection	Fracture Load (kg)
1 Hour	21	2.5	4	0	0.8	1.6	2.8	4.4	7.0				7.5	4.1
	37		3	0	2.5	5.5	13.0						15.0	3.0
24 Hours stored in water at 21°C	21	2.5	3	0	0.5	1.0	1.6	2.2	3.5	4.7			4.9	4.8
	37		2	0	0.7	1.8	3.2	4.9					8.2	4.0
24 Hours stored in air at 21°C	21	2.5	3	0	0.5	1.0	1.6	2.2	3.1	4.2			4.5	4.7
	37		3	0	0.6	1.4	2.4	3.8	6.5				7.4	4.2
72 Hours stored in water at 21°C	21	2.5	3	0	0.5	0.9	1.4	1.7	2.2	2.7	3.4	4.2	4.7	5.7
	37		2	0	0.7	1.4	2.3	3.4	5.0				7.0	4.5
72 Hours stored in air at 21°C	21	2.5	2	0	0.5	0.9	1.4	2.0	2.7	3.5			4.5	5.0
	37		2	0	0.5	1.1	1.8	2.6	4.0				5.8	4.6
1 Week stored in water at 37°C	37	2.5	4	0	0.7	1.4	2.1	3.0	4.3				4.5	4.0

TABLE 4-10.

TRANSVERSE STRENGTH & RIGIDITY.

(Specification Test piece and loading rate.)

Material: Formatray

Test Conditions	Temp. of Test (°C)	Thickness of Specimen (mm)	No. of Tests	Average Deflection (mm) 1500gm	2000gm	2500gm	3000gm	3500gm	4000gm	4500gm	5000gm	5500gm	Maximum Deflection	Fracture Load (kg)
1 Hour	21	2.5	3	0	0.7	1.4	2.7						2.9	3.0
	37		4	0	2.6	9.0							11.0	2.6
24 Hours stored in water at 21°C	21	2.5	2	0	0.4	0.8	1.4	2.0	2.6				2.7	4.0
	37		3	0	0.8	1.8	4.0	9.0					9.0	3.5
24 Hours stored in air at 21°C	21	2.5	2	0	0.3	0.7	1.1	1.6	2.2				2.4	4.1
	37		4	0	0.6	1.2	2.1	3.7					4.2	3.5
72 Hours stored in water at 21°C	21	2.5	2	0	0.4	0.8	1.2	1.8	2.3				2.5	4.0
	37		2	0	0.6	1.4	2.4	4.6					5.6	3.8
72 Hours stored in air at 21°C	21	2.5	2	0	0.3	0.7	1.0	1.5	2.0				2.7	4.5
	37		3	0	0.4	0.9	1.5	2.5	4.0				4.1	4.0
1 Week stored in water at 37°C	37	2.5	4	0	0.7	1.4	2.1	3.0	4.3				4.5	4.0
Specimens prepared according to the proposed revision of B.S. 2847.														
72 Hours stored in air at 21°C	21	2.5	2	0	0.3	0.7	1.0	1.5	1.9	2.6			2.6	4.8
72 Hours stored in water at 21°C	21	2.5	2	0	0.4	0.8	1.3	1.8	2.5				3.0	4.5

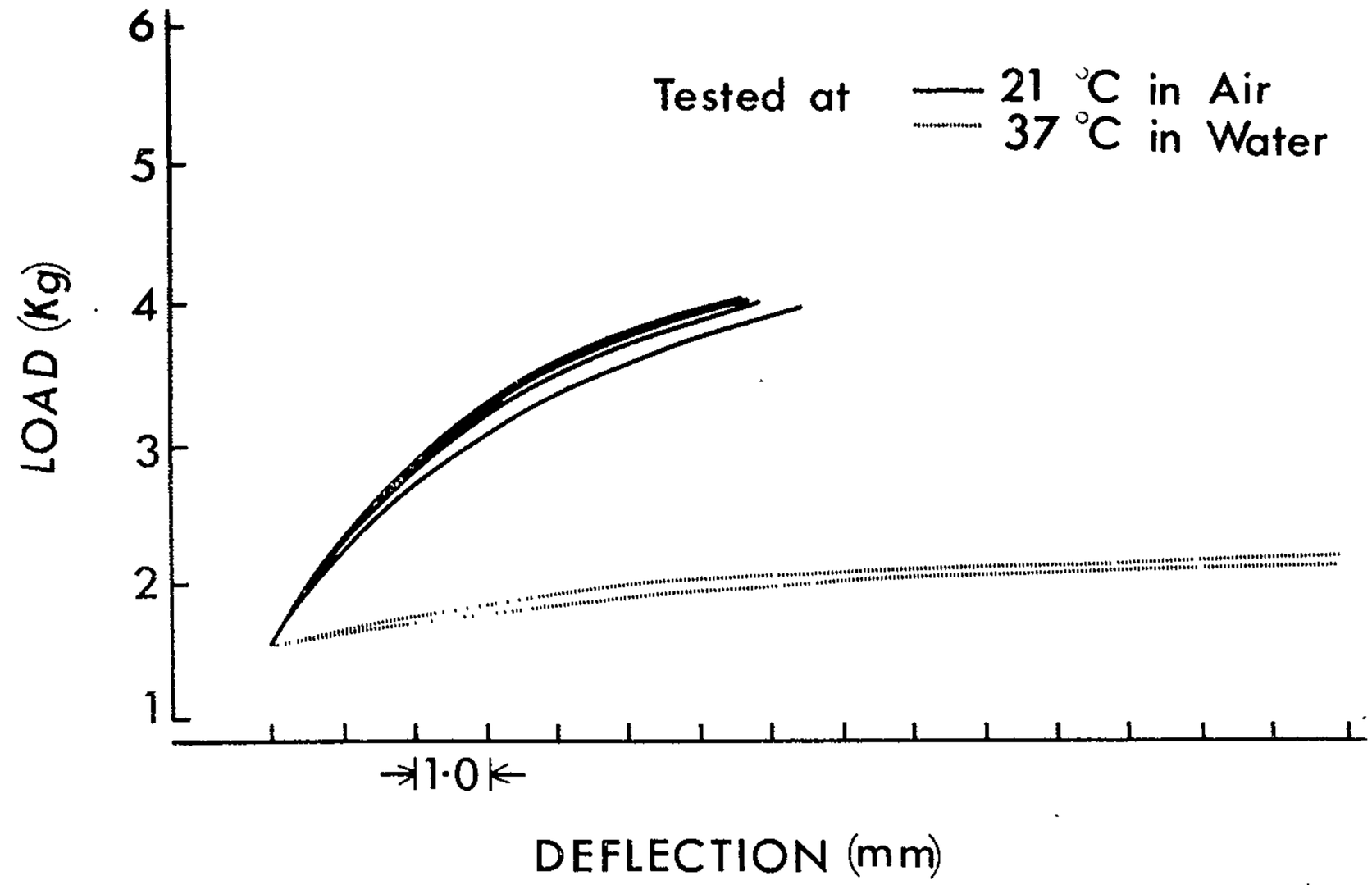


Figure 4-9

Load-deflection graph for Trayresin; Tested one hour after mixing.

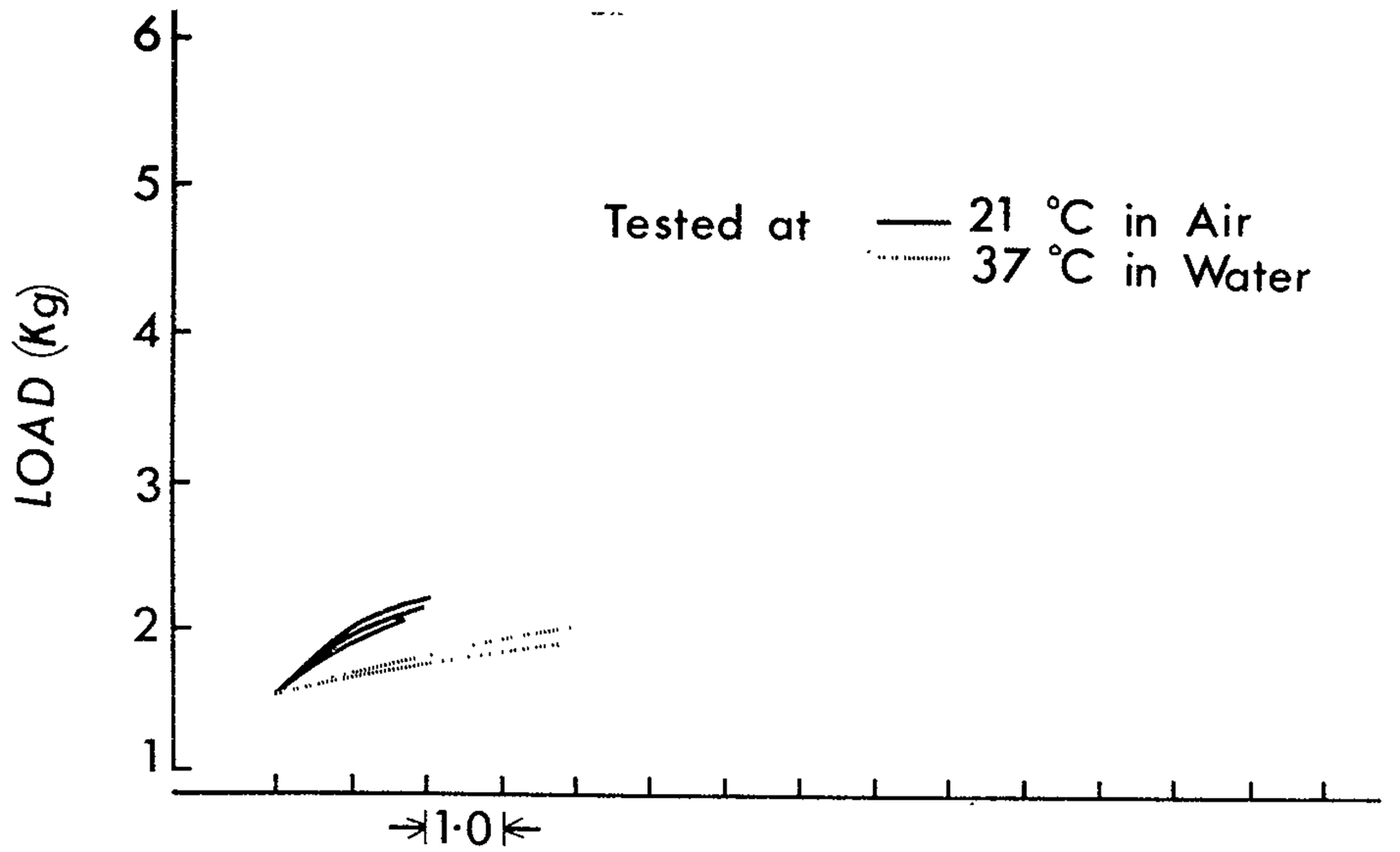


Figure 4-10

Load-deflection graph for Tray Plastic; Tested one hour after mixing.

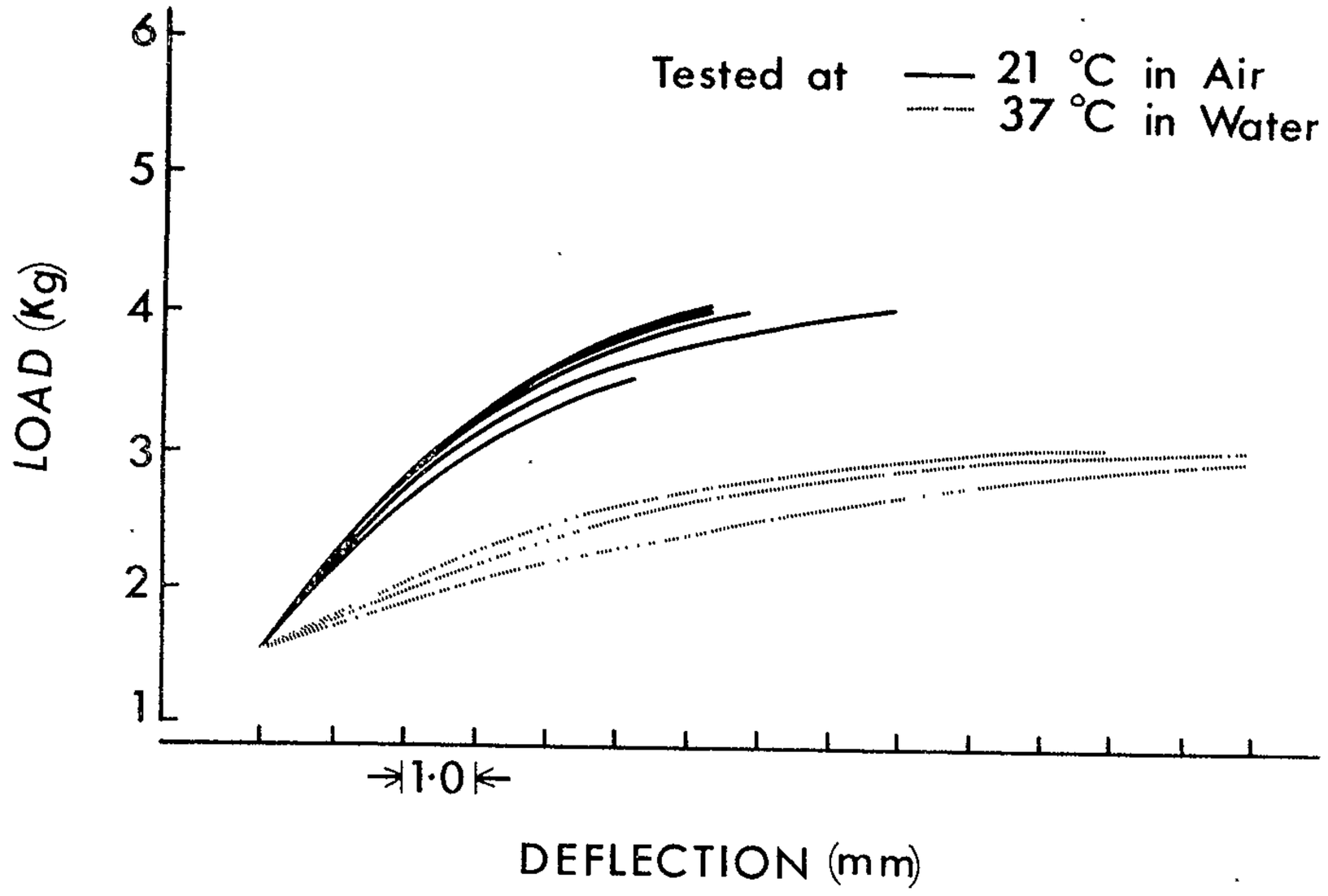


Figure 4-11

Load-deflection graph for Traybase; Tested one hour after mixing.

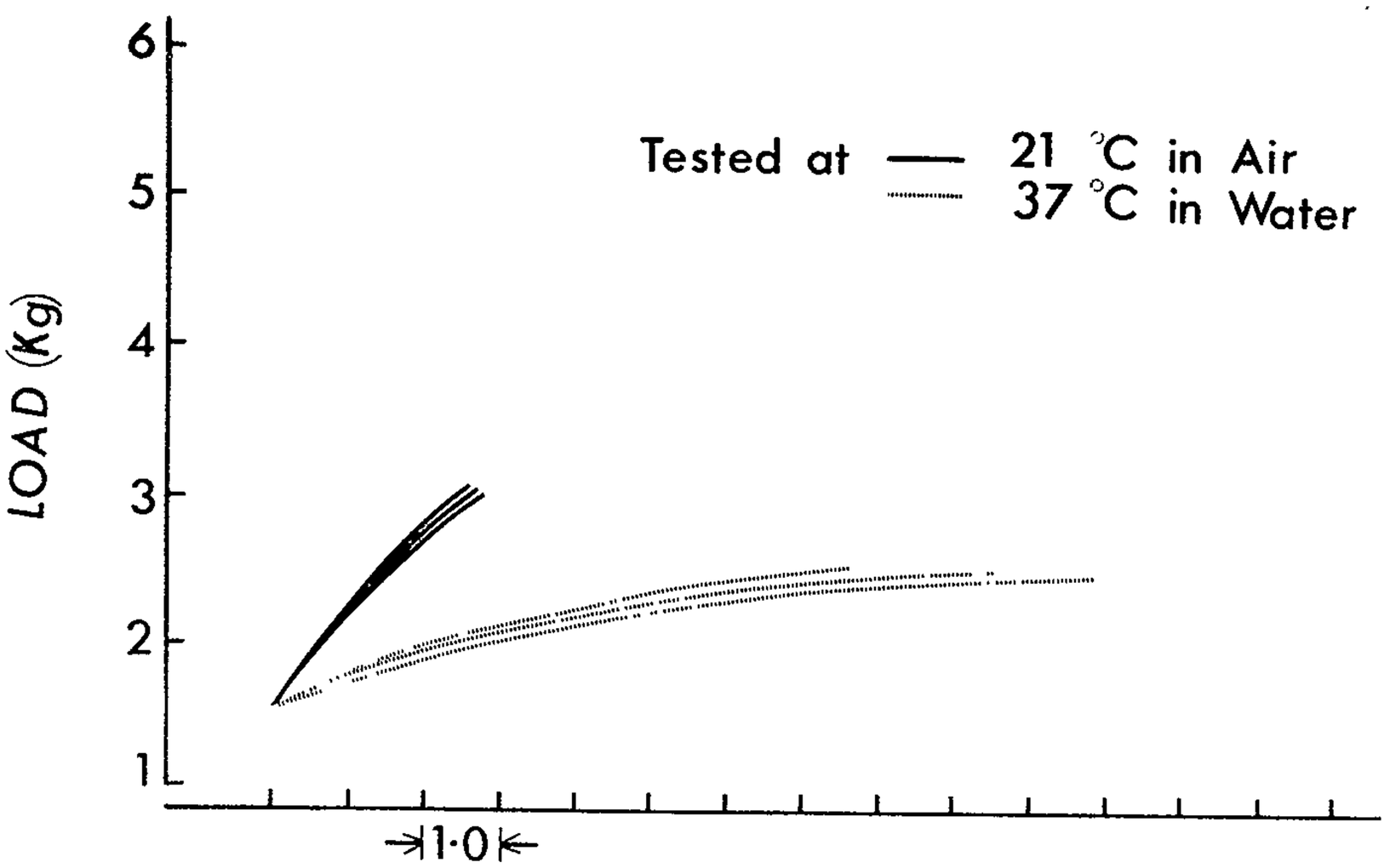


Figure 4-12

Load-deflection graph for Formatray; Tested one hour after mixing.

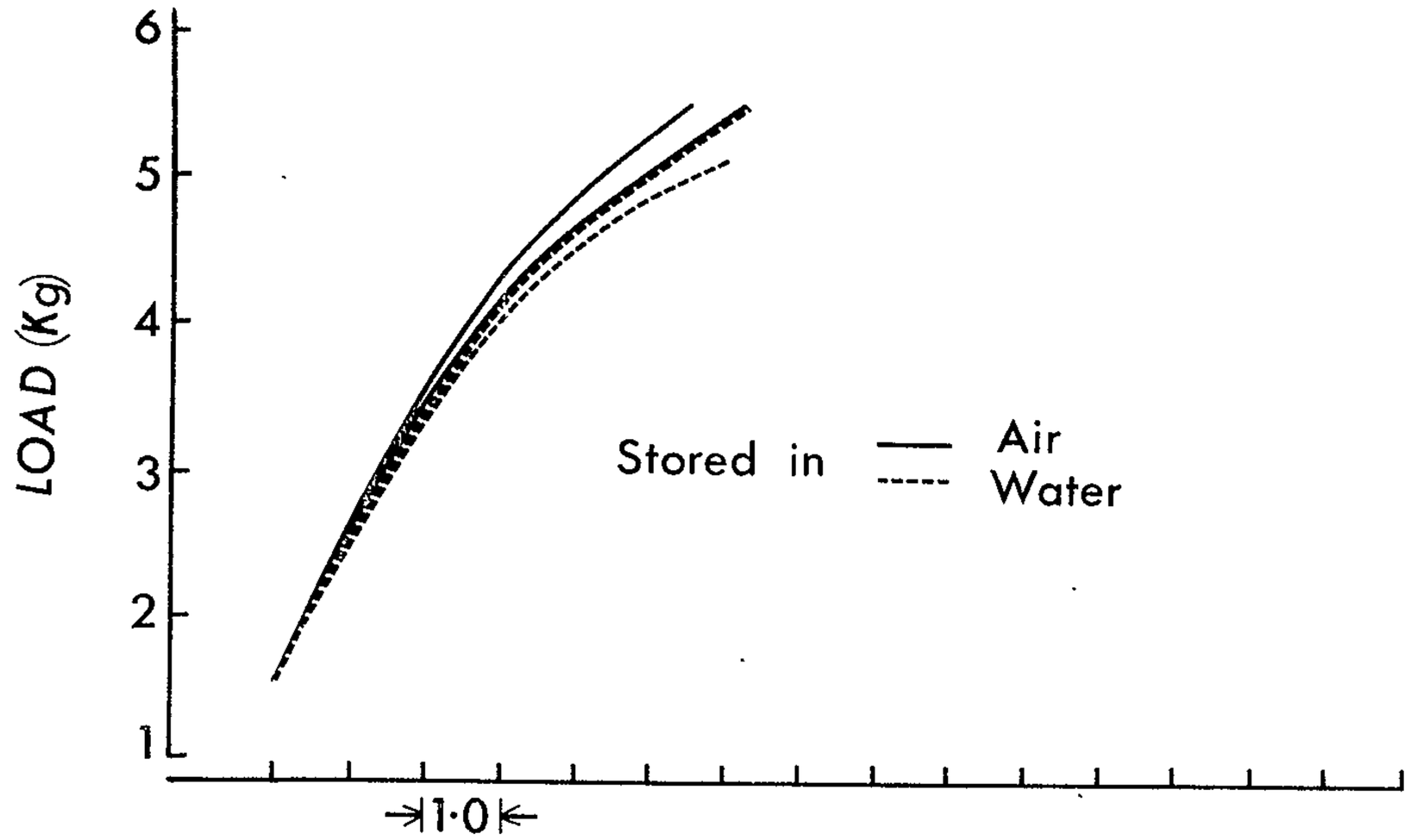


Figure 4-13

Load-deflection graph for Trayresin; Tested at 21°C in air, following 24 hours' storage.

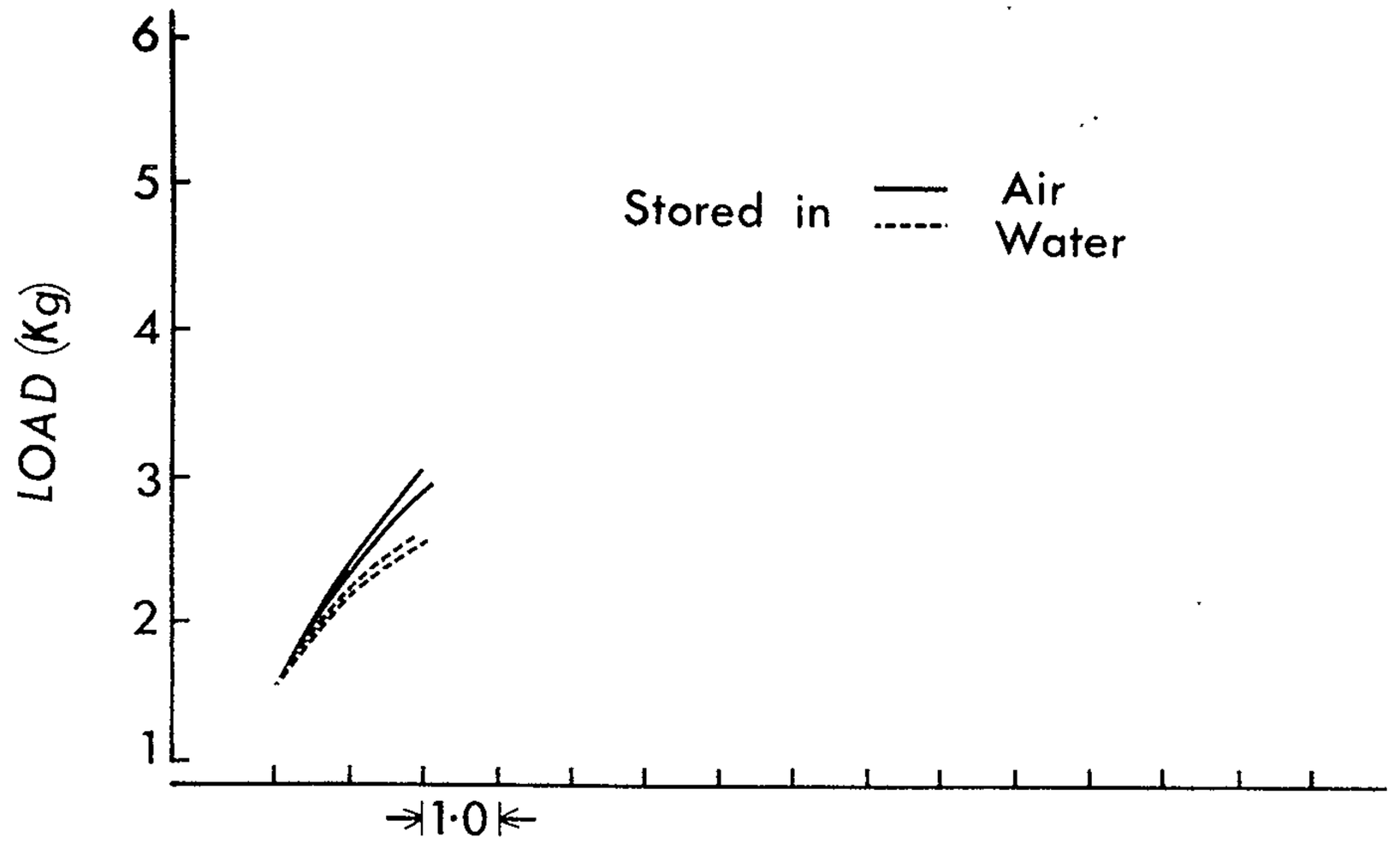


Figure 4-14

Load-deflection graph for Tray Plastic; Tested at 21°C in air, following 24 hours' storage.

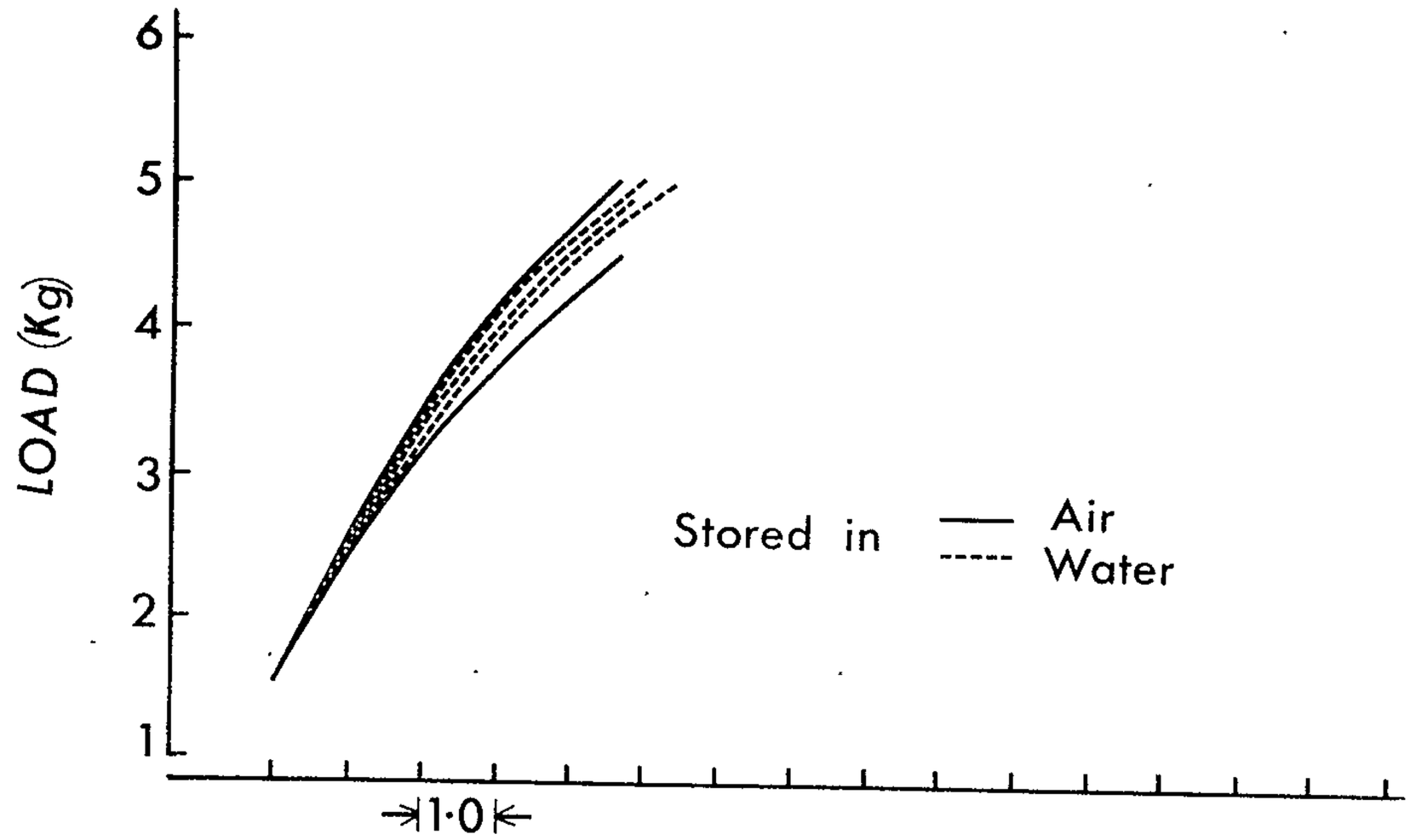


Figure 4-15

Load-deflection graph for Traybase; Tested at 21°C in air, following 24 hours' storage.

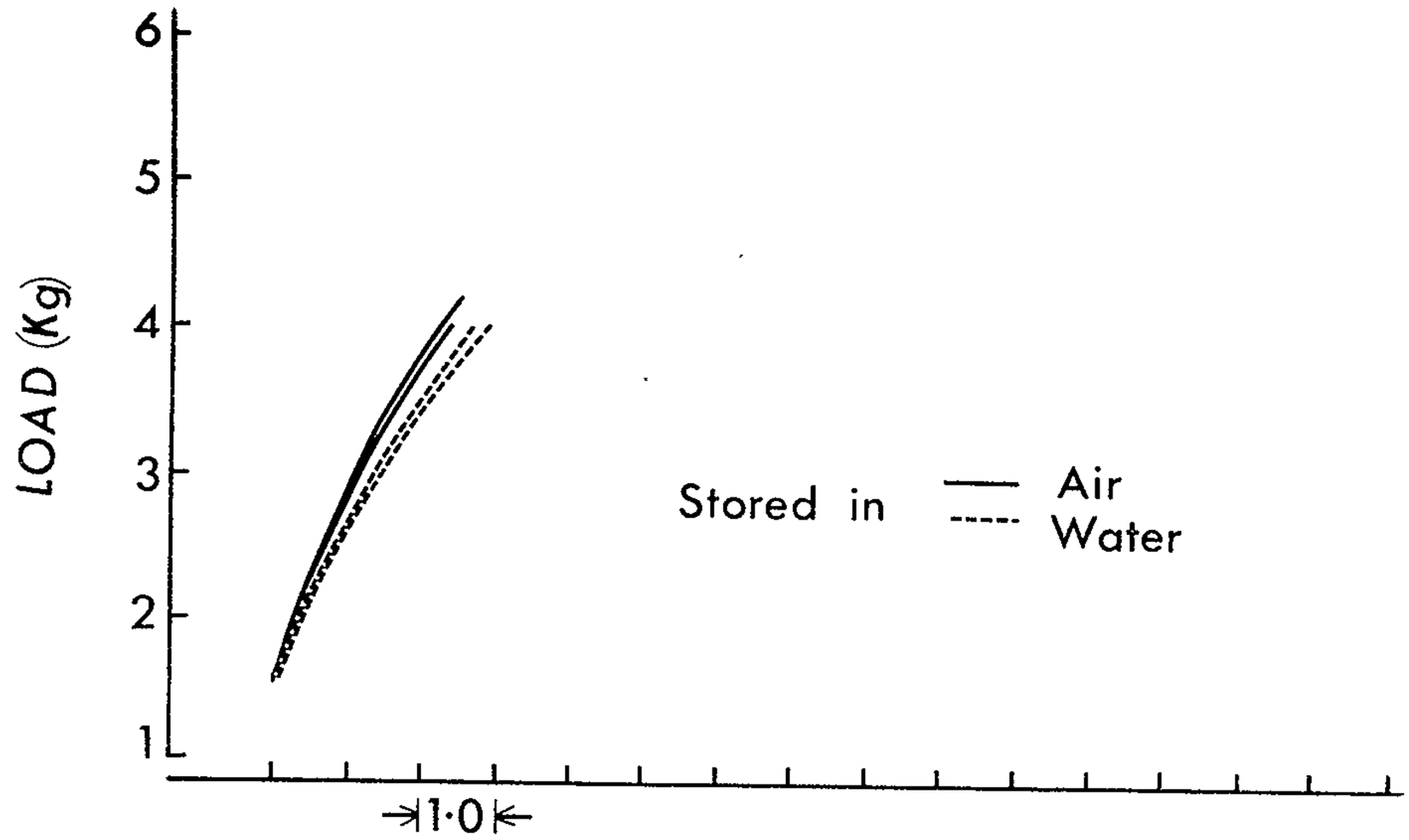


Figure 4-16

Load-deflection graph for Formatray; Tested at 21°C in air, following 24 hours' storage.

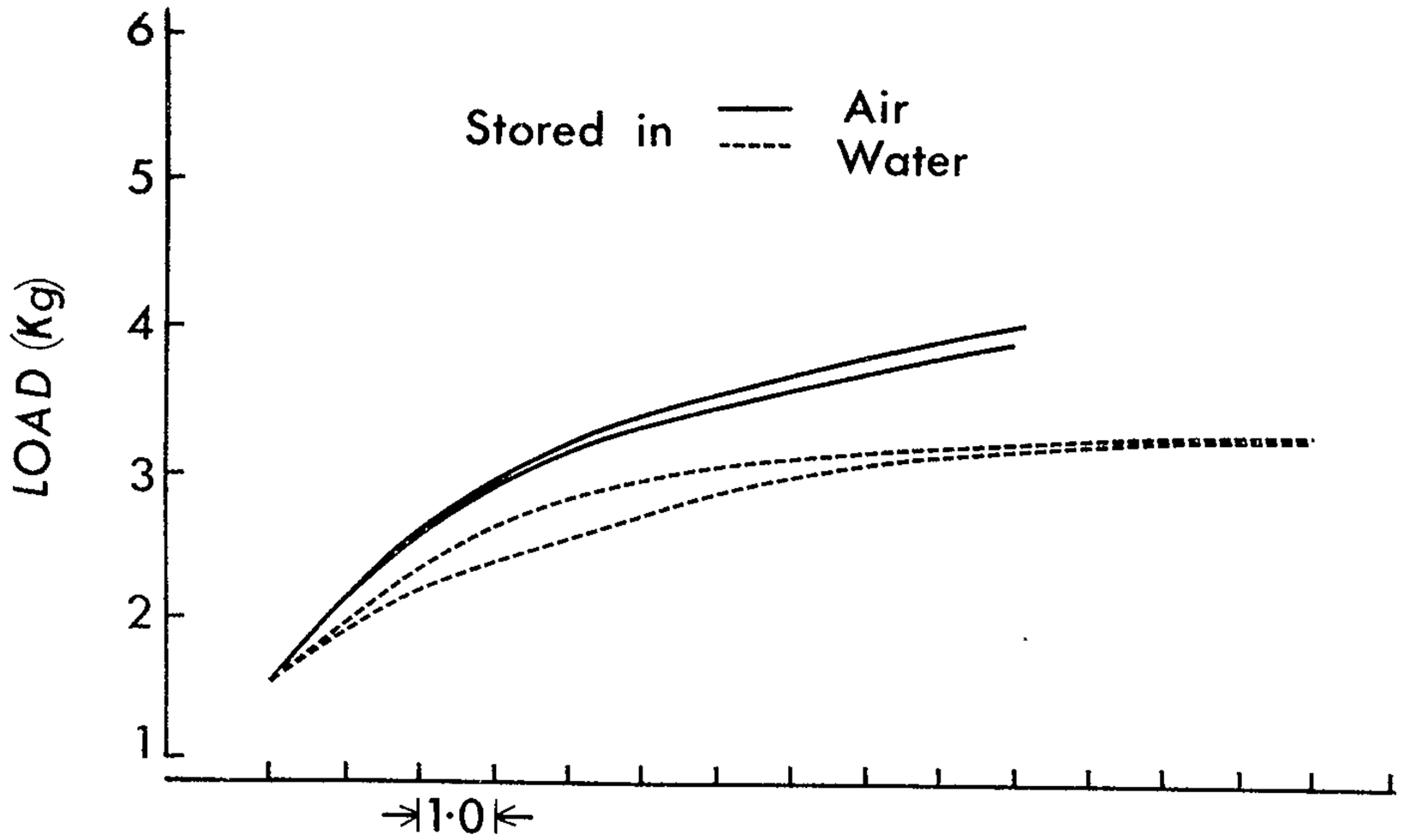


Figure 4-17

Load-deflection graph for Trayresin; Tested at 37°C in water, following 24 hours' storage.

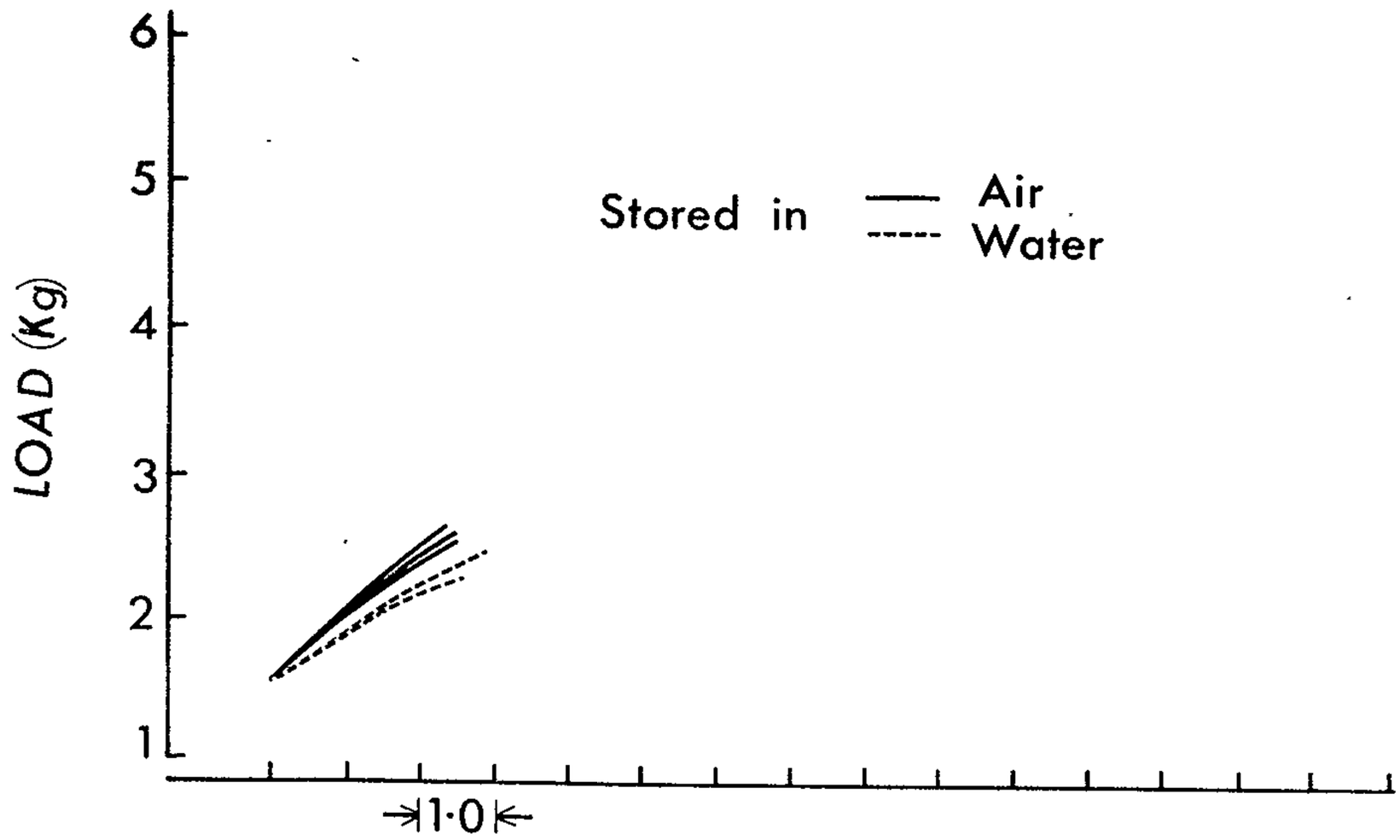


Figure 4-18

Load-deflection graph for Tray Plastic; Tested at 37°C in water, following 24 hours' storage.

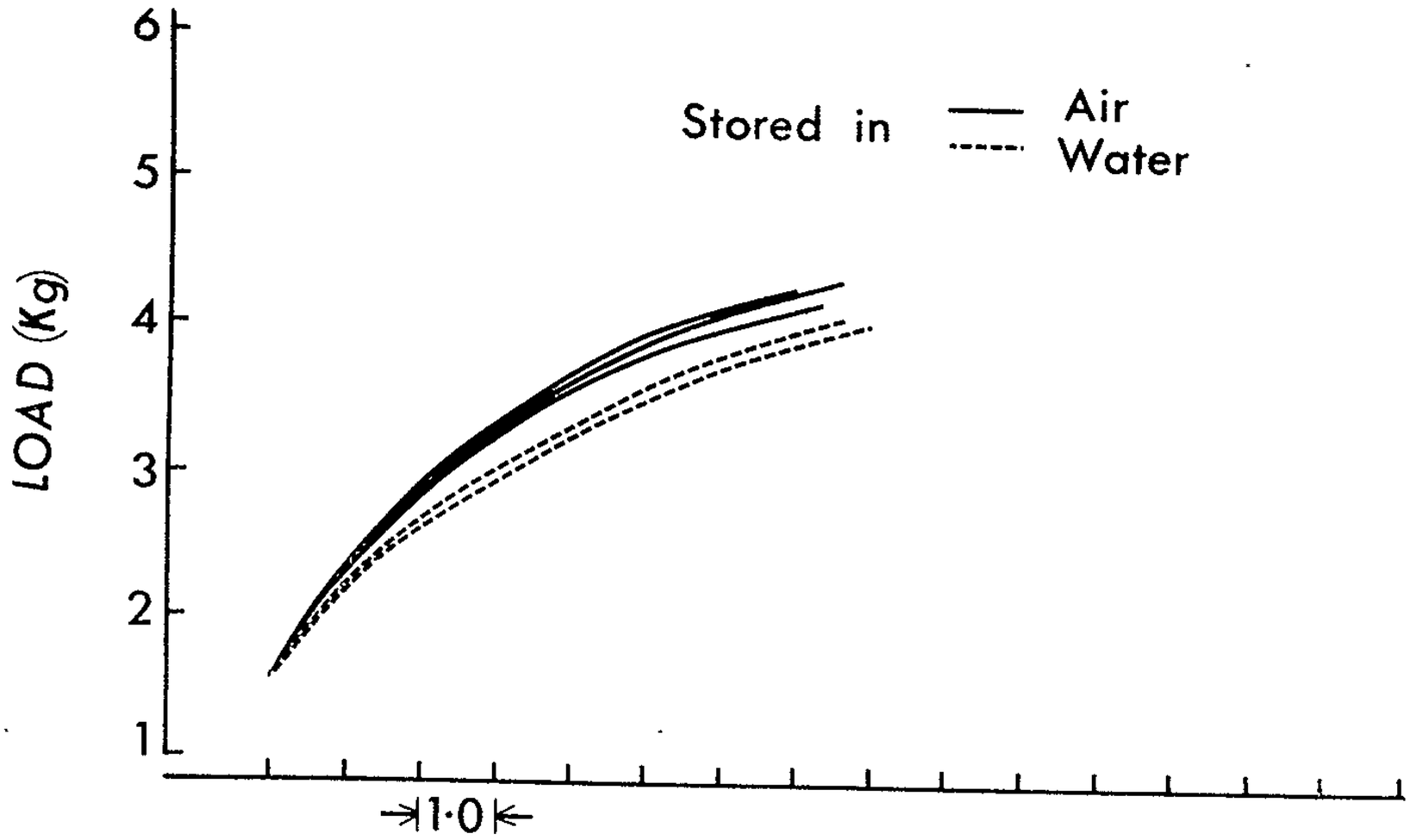


Figure 4-19

Load-deflection graph for Traybase; Tested at 37°C in water, following 24 hours' storage.

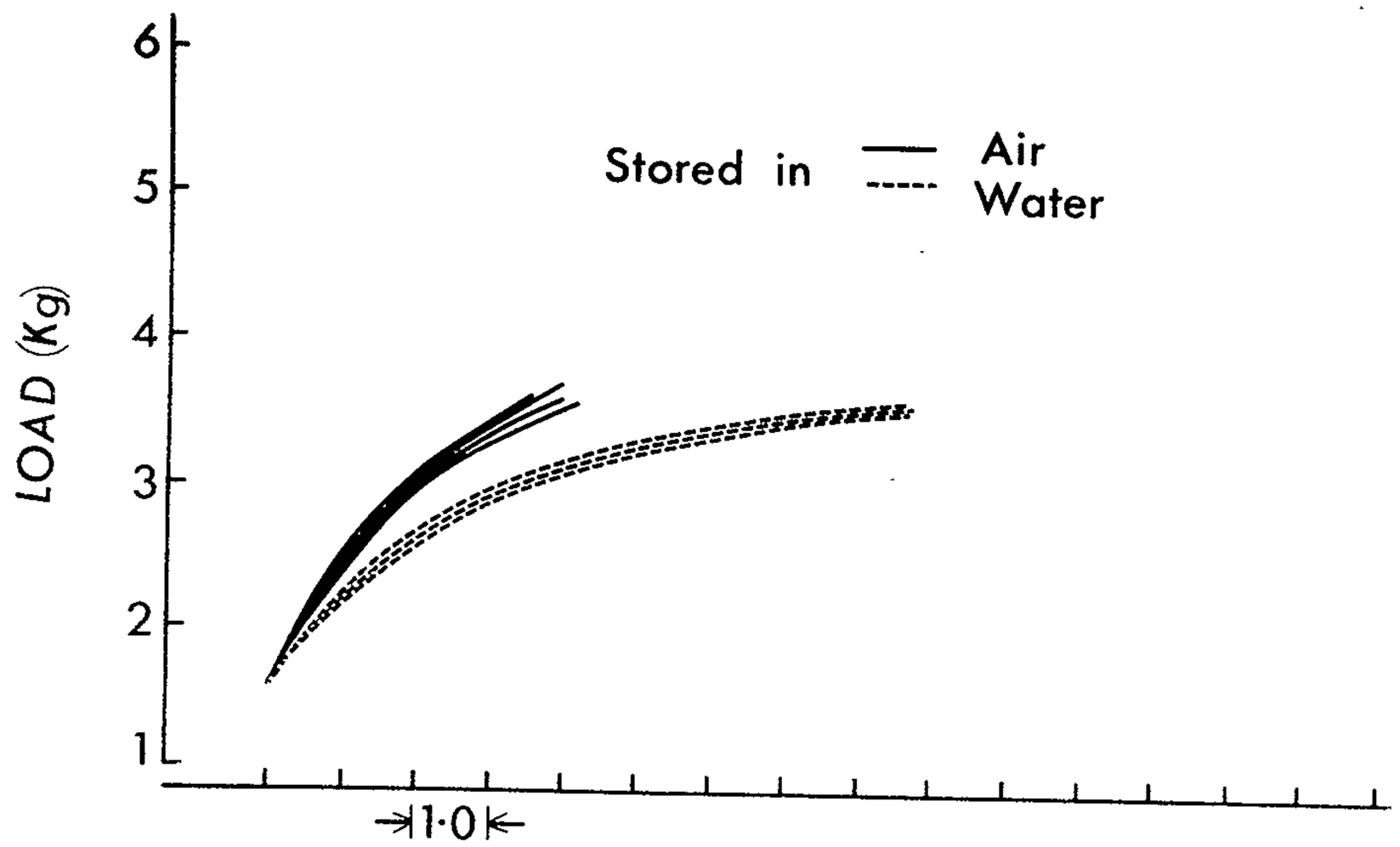


Figure 4-20

Load-deflection graph for Formatray; Tested at 37°C in water, following 24 hours' storage.

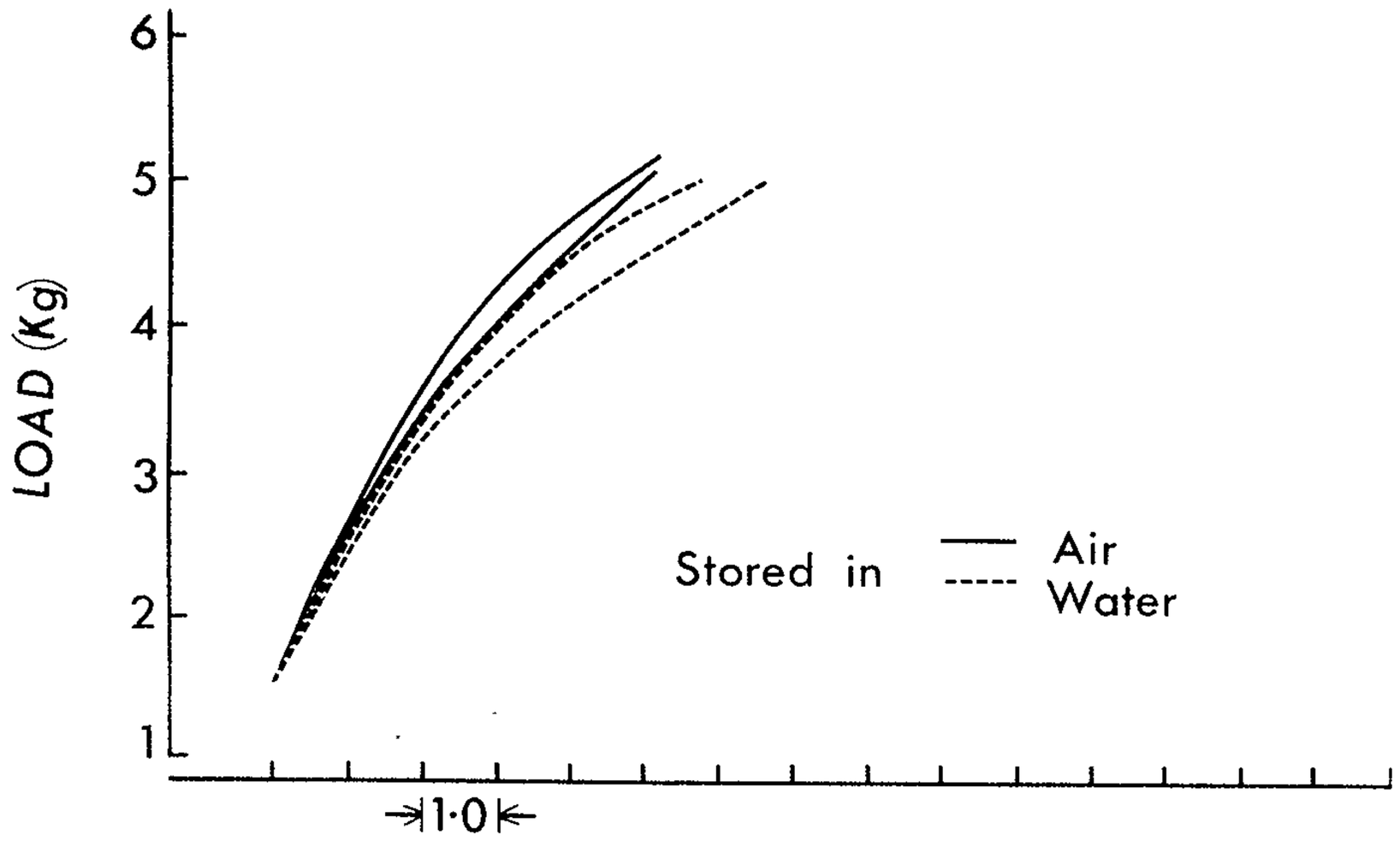


Figure 4-21

Load-deflection graph for Trayresin; Tested at 21°C in air, following 72 hours' storage.

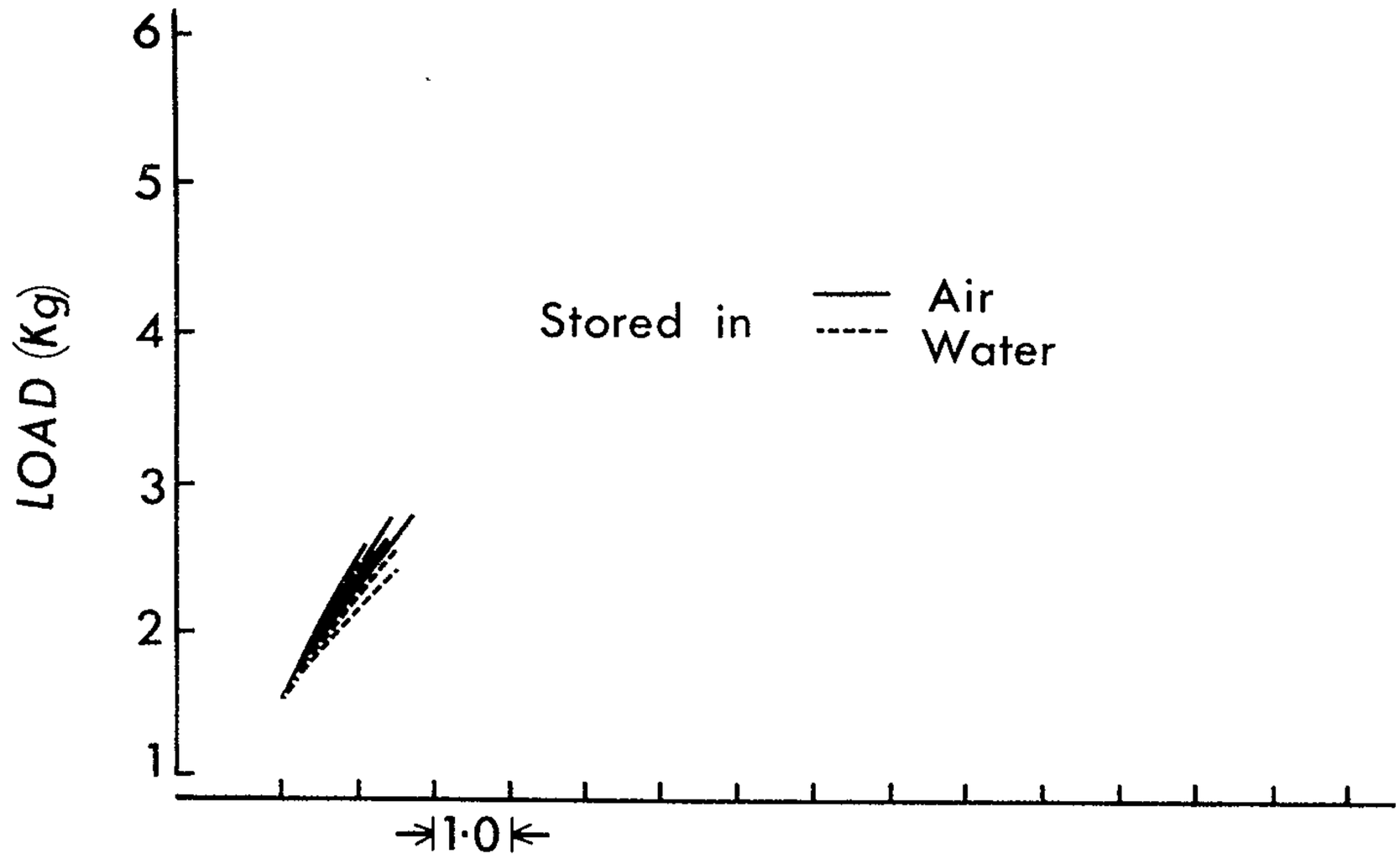


Figure 4-22

Load-deflection graph for Tray Plastic; Tested at 21°C in air, following 72 hours' storage.

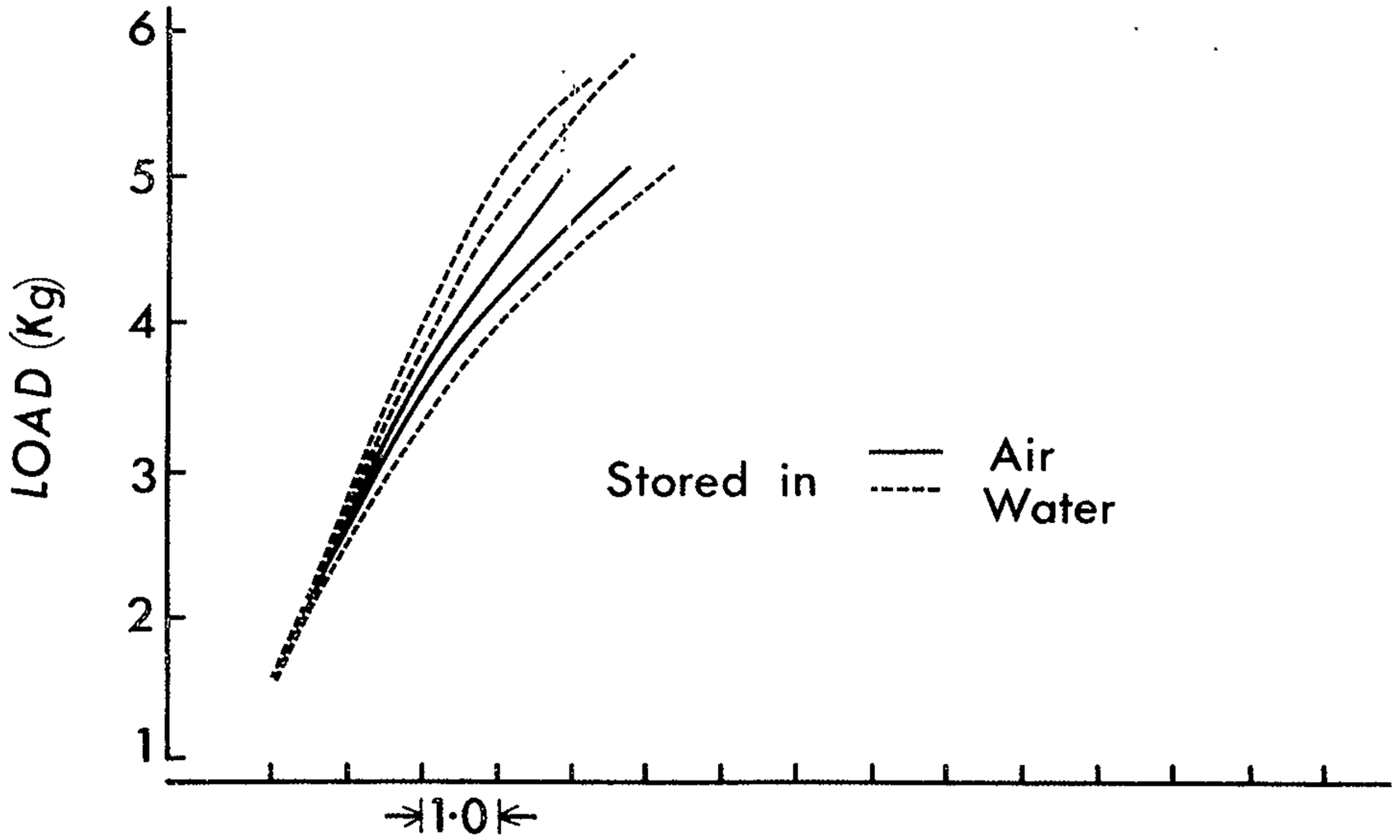


Figure 4-23

Load-deflection graph for Traybase; Tested at 21°C in air, following 72 hours' storage.

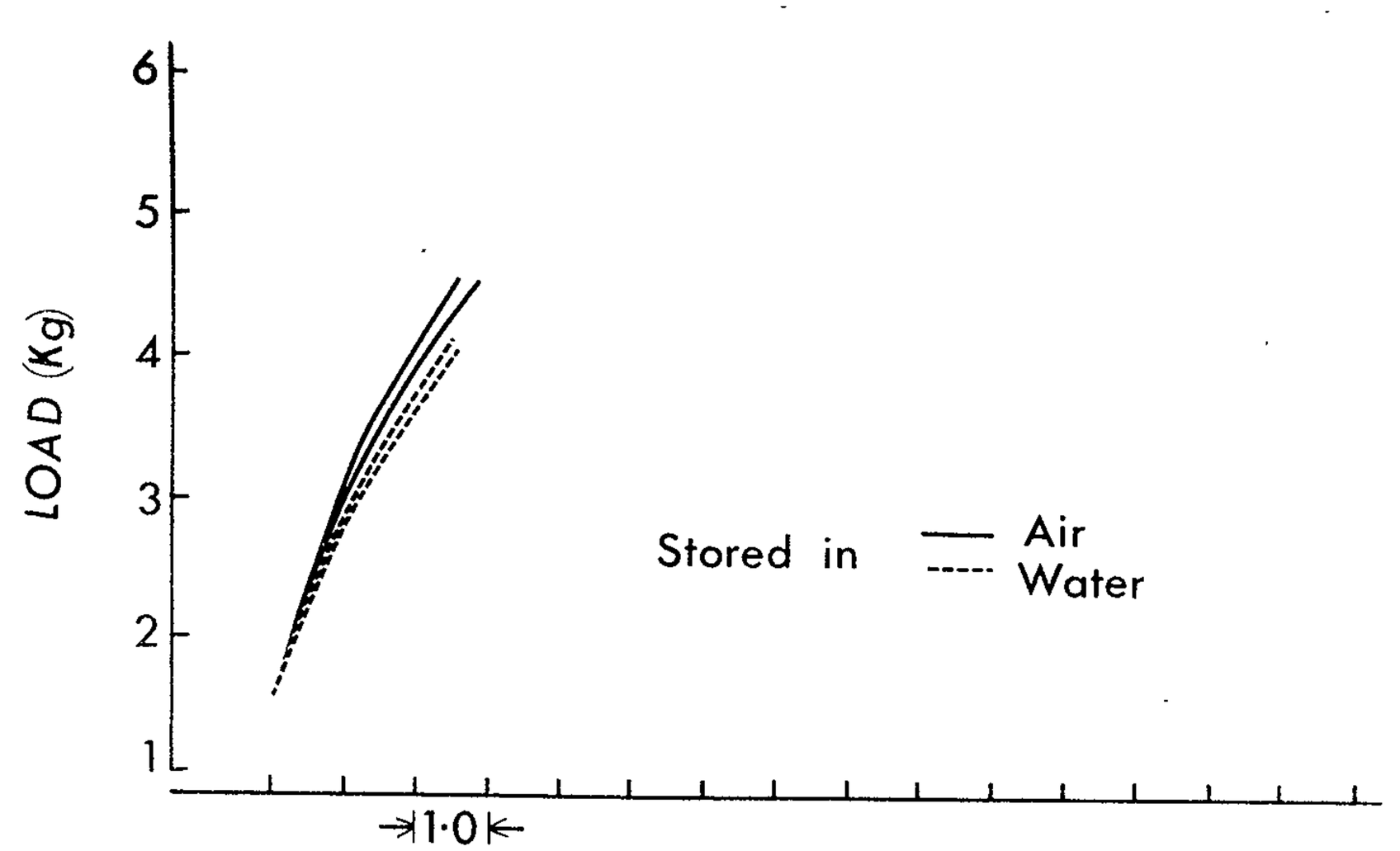


Figure 4-24

Load-deflection graph for Formatray; Tested at 21°C in air, following 72 hours' storage.

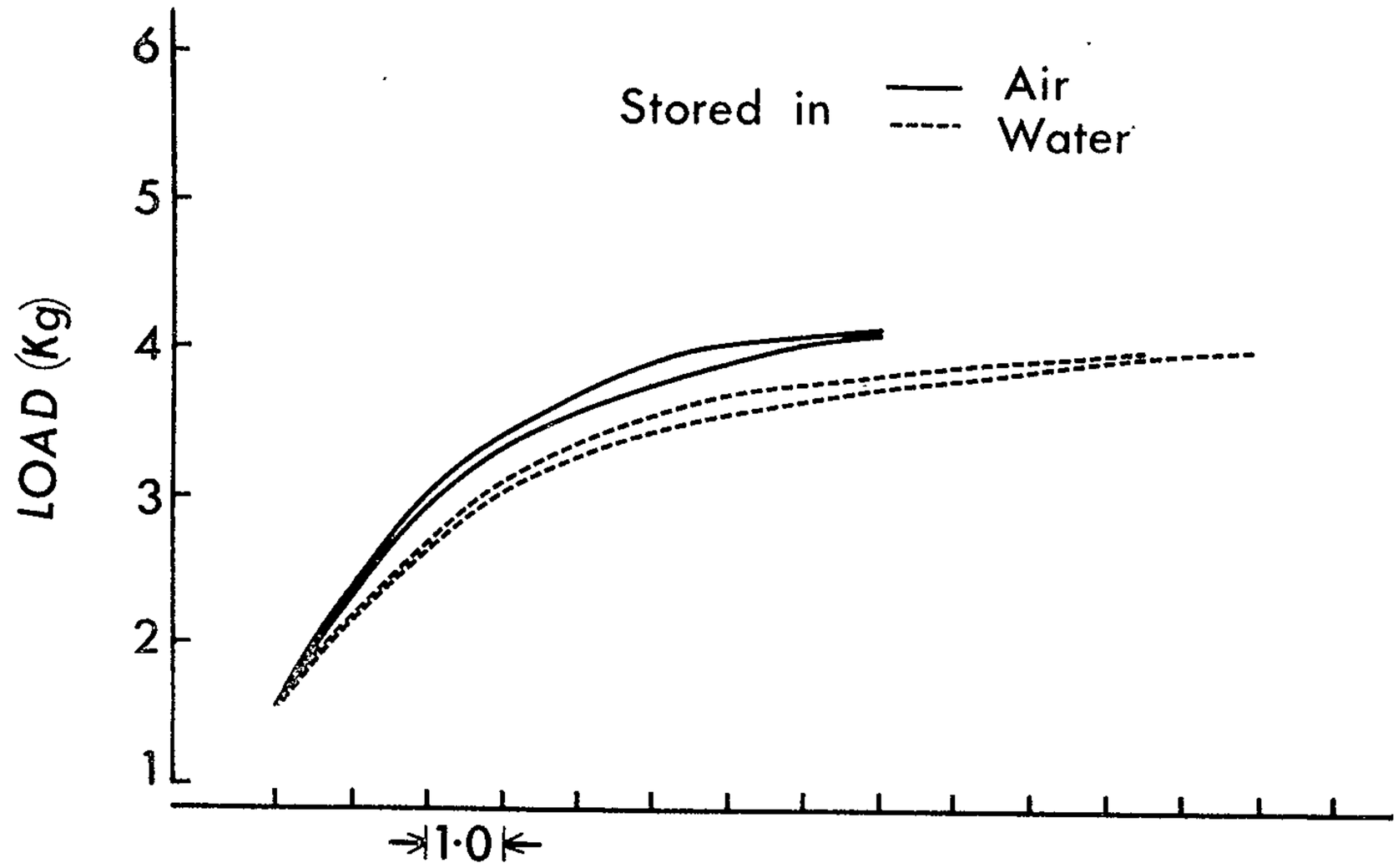


Figure 4-25

Load-deflection graph for Trayresin; Tested at 37°C in water, following 72 hours' storage.

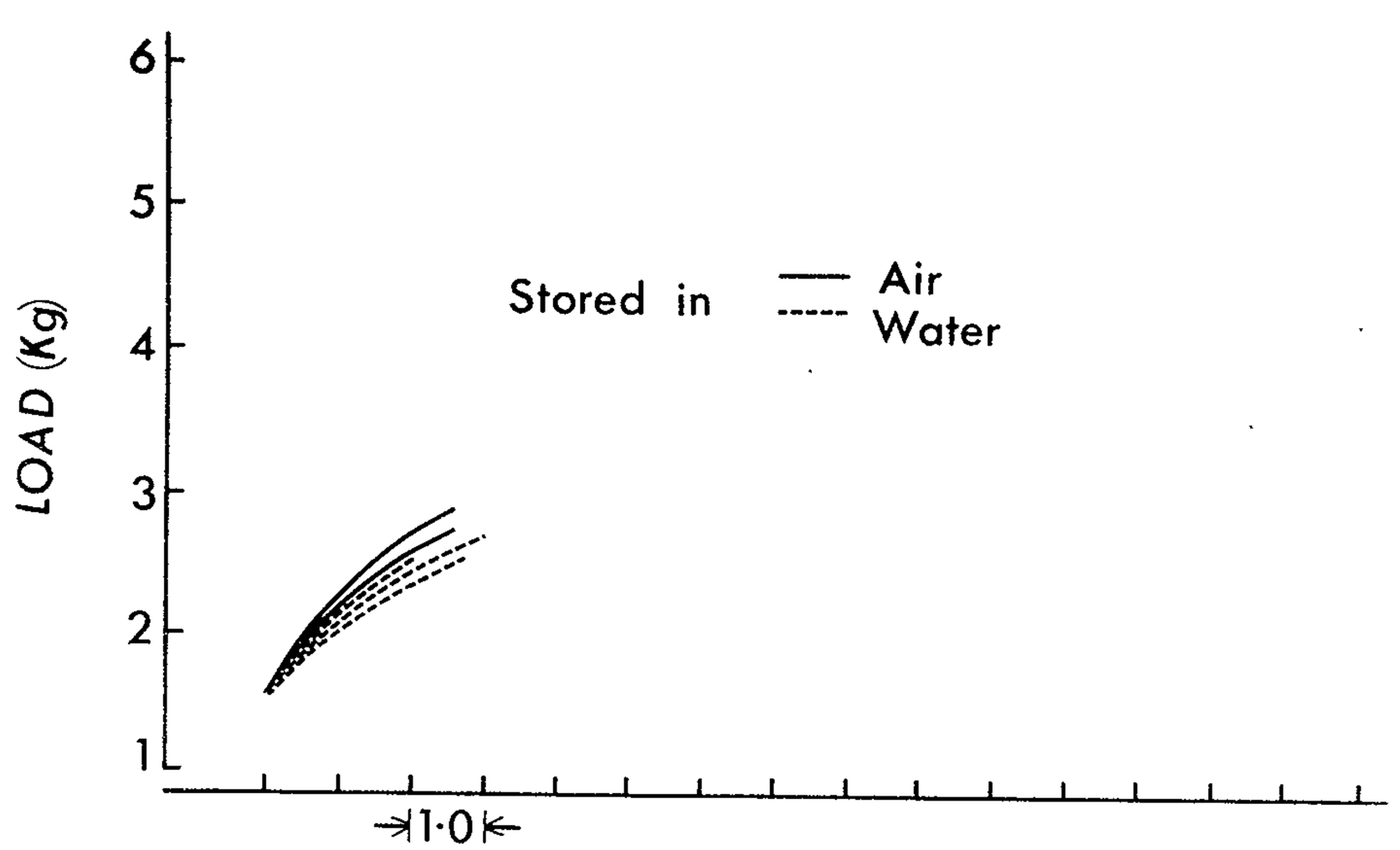


Figure 4-26

Load-deflection graph for Tray Plastic; Tested at 37°C in water, following 72 hours' storage.

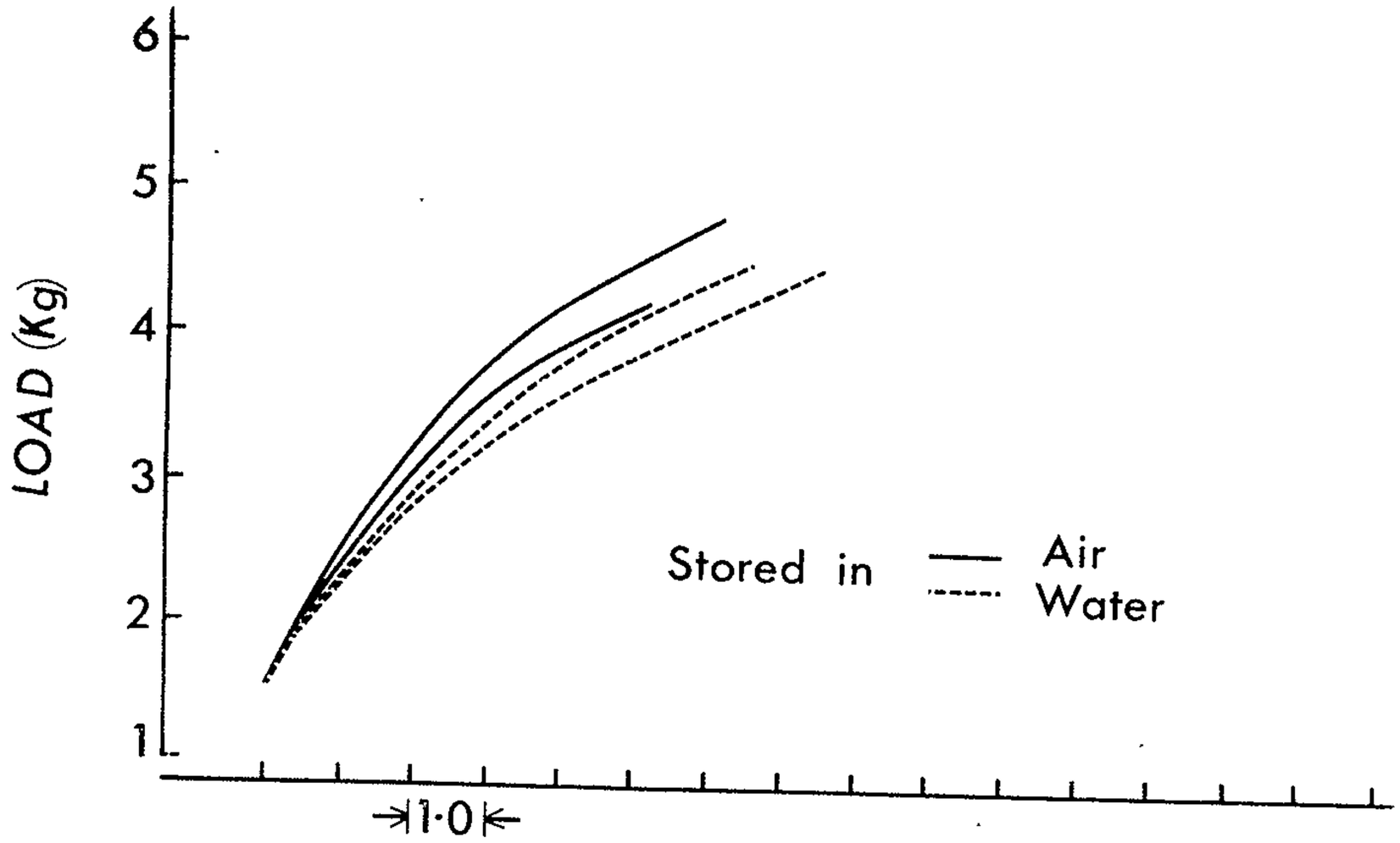


Figure 4-27

Load-deflection graph for Traybase; Tested at 37°C in water, following 72 hours' storage.

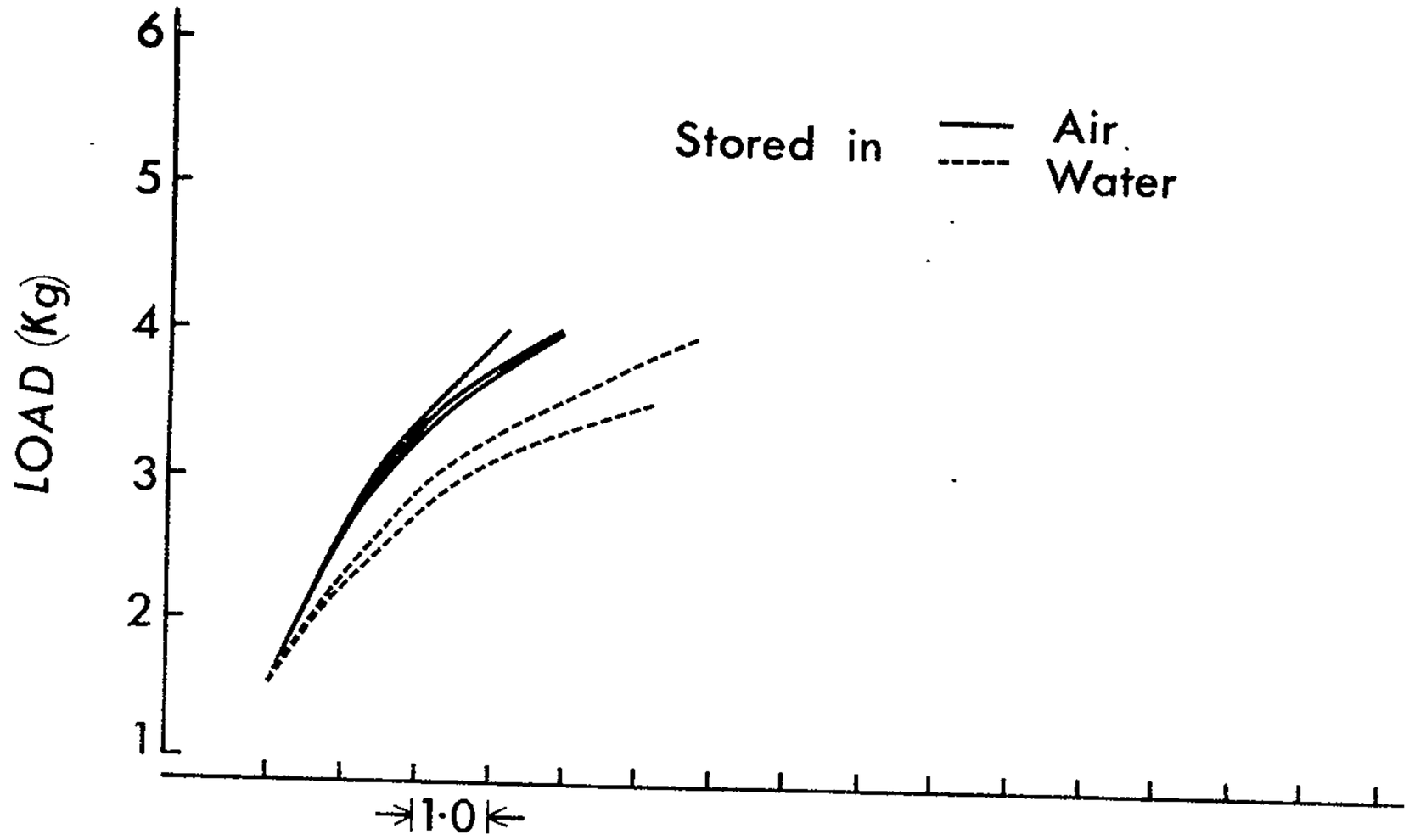


Figure 4-28

Load-deflection graph for Formatray; Tested at 37°C in water, following 72 hours' storage.

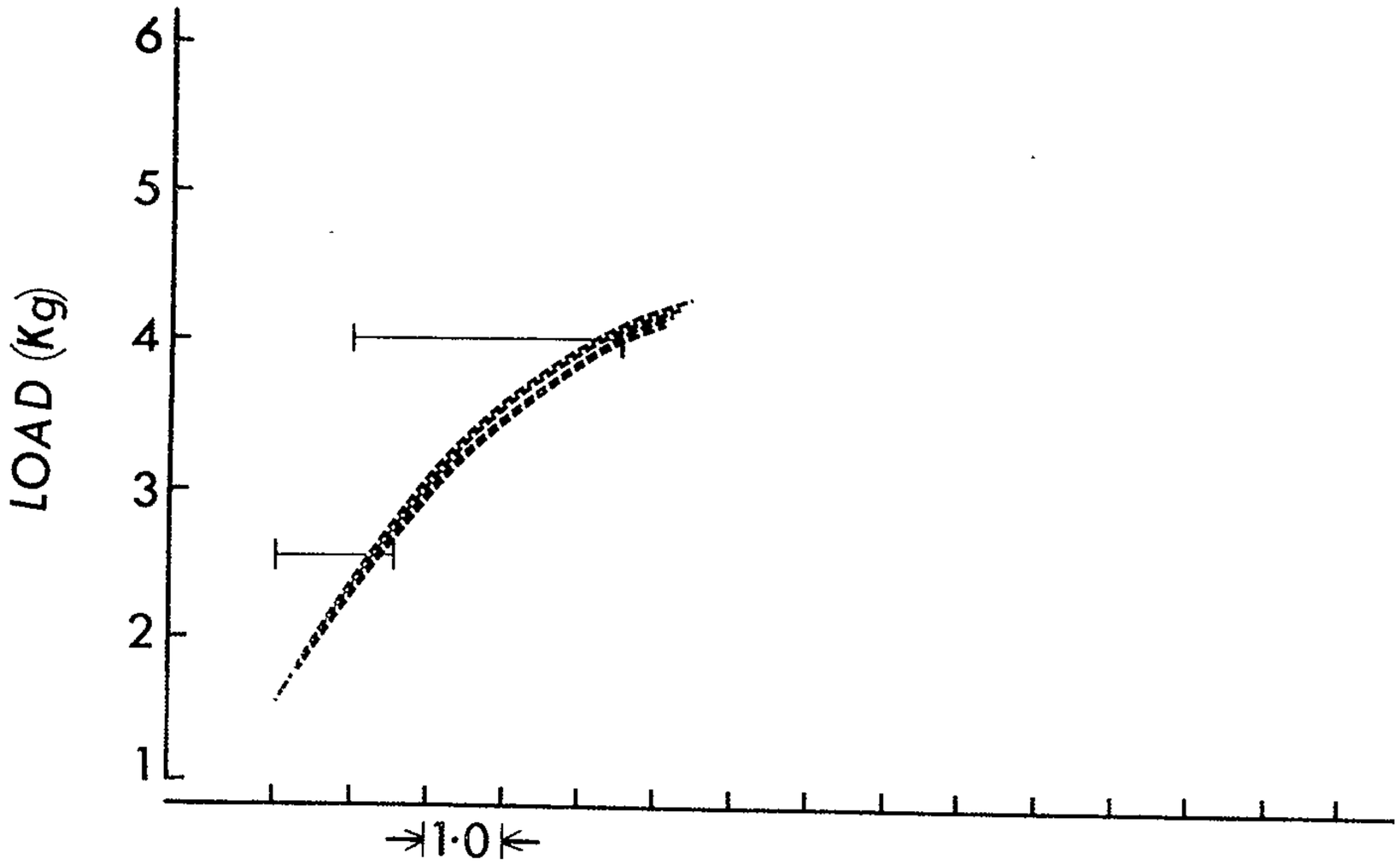


Figure 4-29

Load-deflection graph for Trayresin; Tested at 37°C in water following storage for one week in water at 37°C.

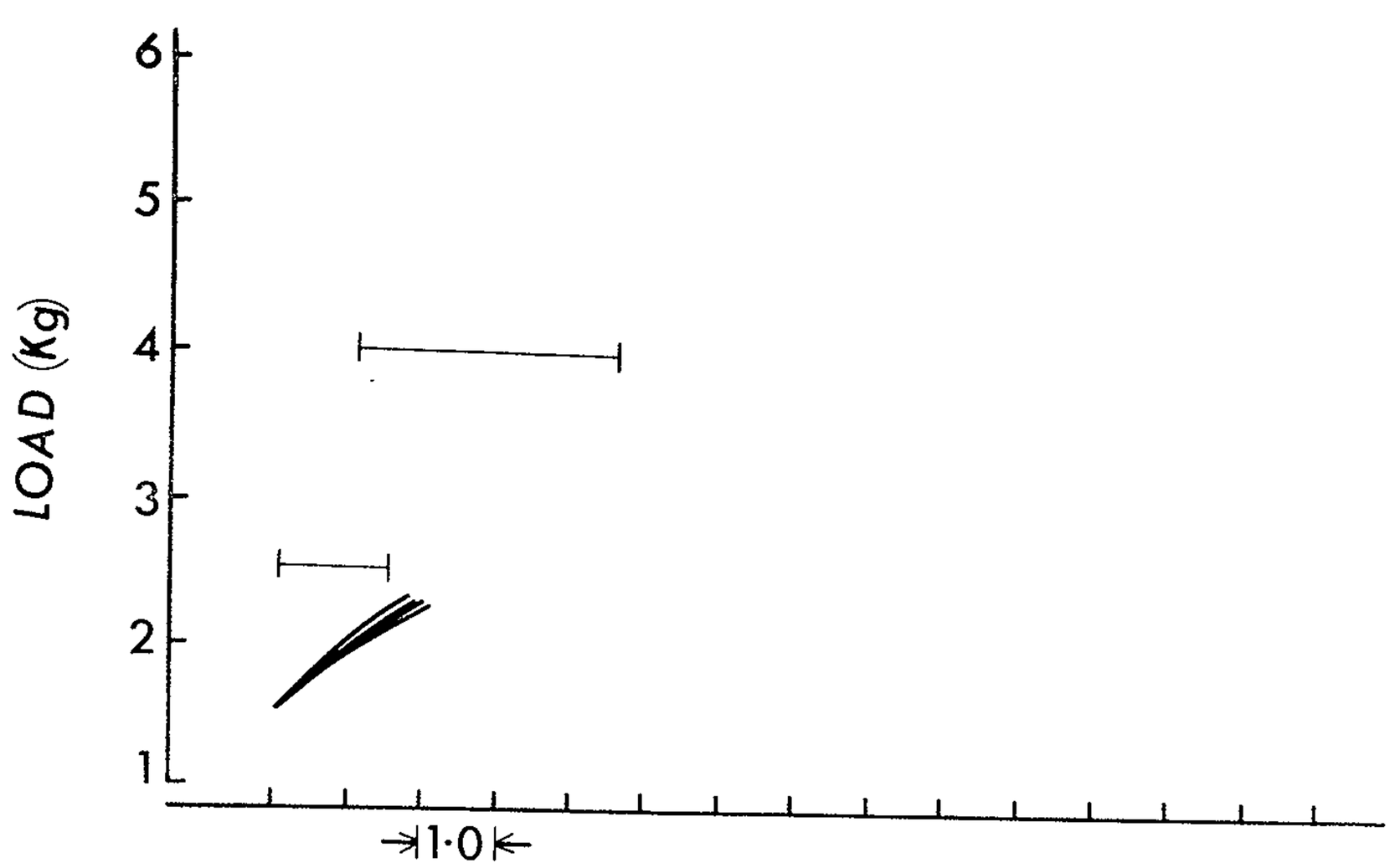


Figure 4-30

Load-deflection graph for Tray Plastic; Tested at 37°C in water following storage for one week in water at 37°C.

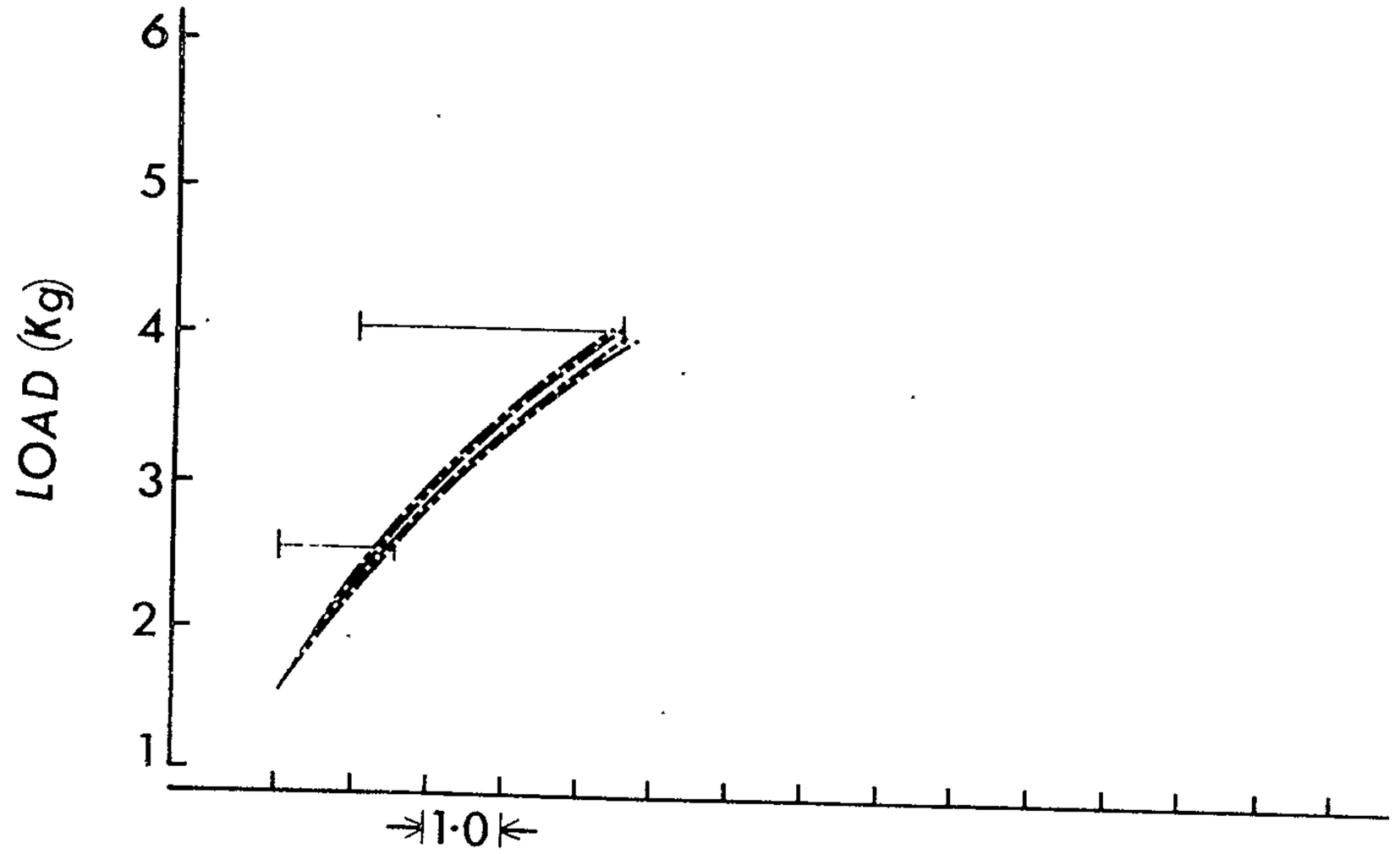


Figure 4-31

Load-deflection graph for Traybase; Tested at 37°C in water following storage for one week in water at 37°C.

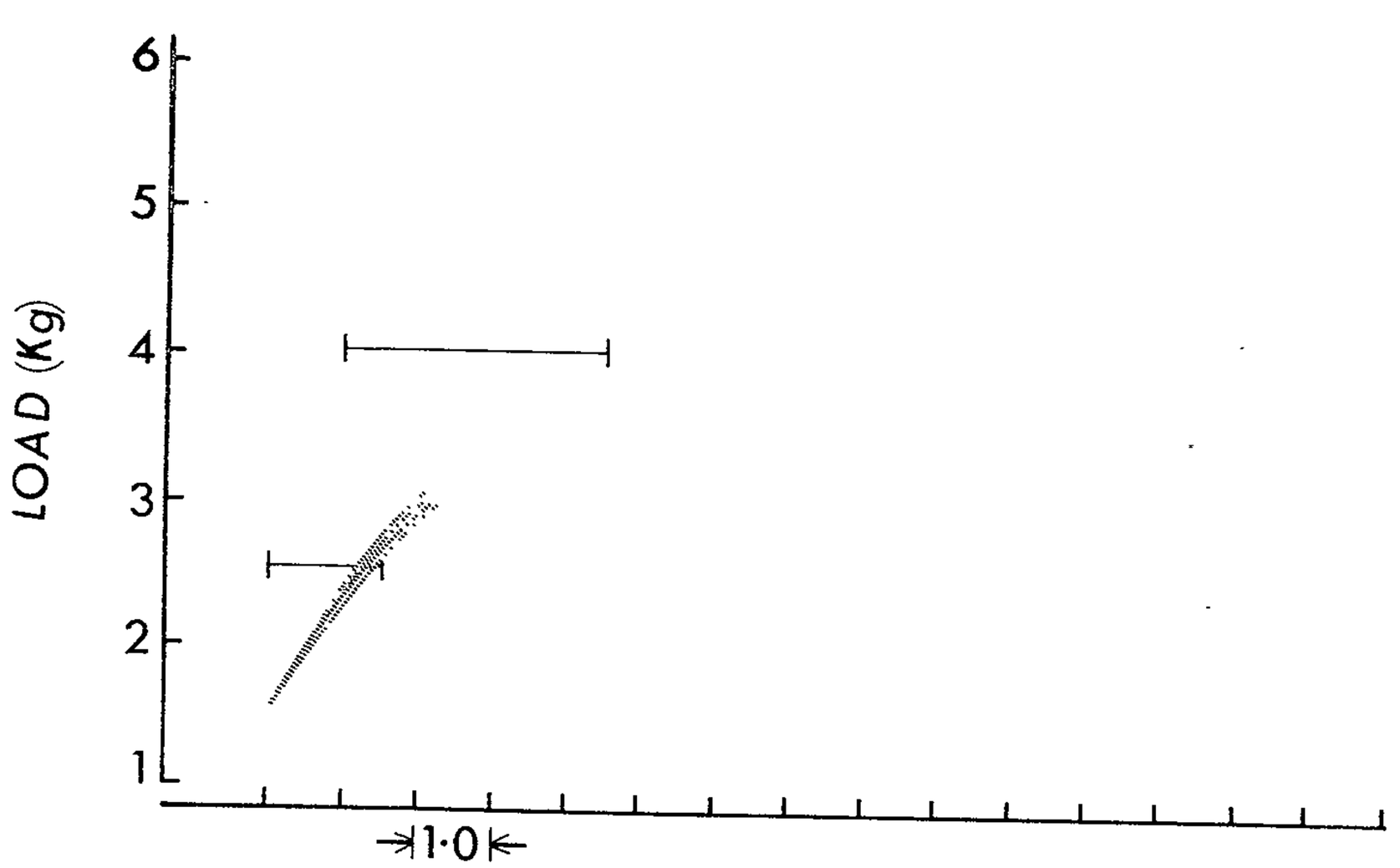


Figure 4-32

Load-deflection graph for Formatray; Tested at 37°C in water following storage for one week in water at 37°C.

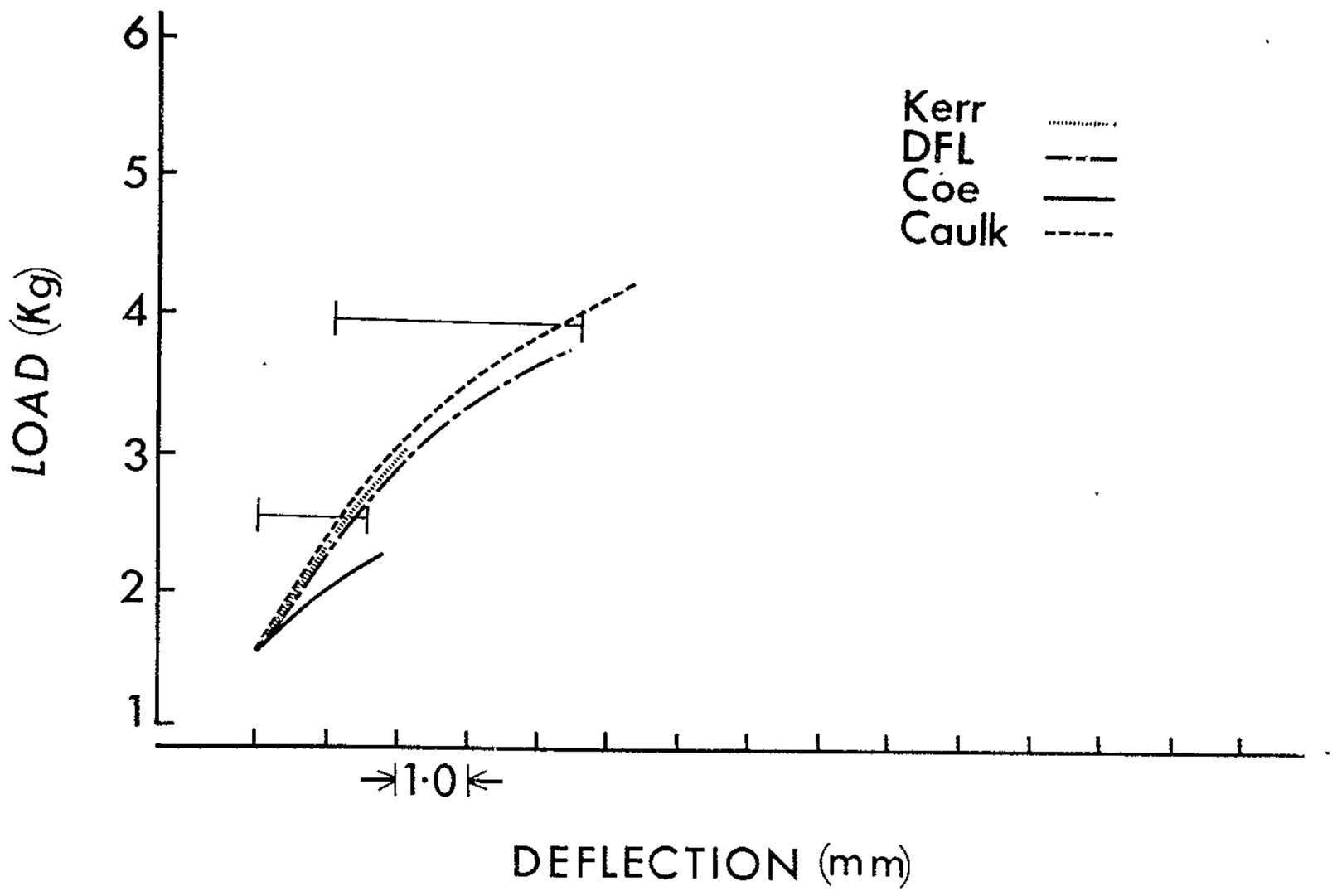


Figure 4-33

Load-deflection graph for each material; Tested at 37°C in water following storage for one week in water at 37°C.

4.5.2. Flow:

The results of flow tests are presented in Table 4-12. The values recorded represent the mean of at least two tests; results for one material under one set of conditions did not vary by more than $\pm$ 0.1 per cent.

TABLE 4-12.

FLOW

Material	Conditions of Storage Before Test	Flow (per cent.). In Water at 37°C	Flow (per cent.). In Air at 21°C
Trayresin	1 Hour in air 21°C	0.6	0.0
	24 Hours in air 21°C	0.2	0.0
	24 Hours in water 21°C	0.2	0.0
	72 Hours in air 21°C	0.2	0.0
	72 Hours in water 21°C	0.2	0.0
Tray Plastic	1 Hour in air 21°C	0.2	0.0
	24 Hours in air 21°C	0.0	0.0
	24 Hours in water 21°C	0.0	0.0
	72 Hours in air 21°C	0.0	0.0
	72 Hours in water 21°C	0.0	0.0
Traybase	1 Hour in air 21°C	0.2	0.0
	24 Hours in air 21°C	0.1	0.0
	24 Hours in water 21°C	0.1	0.0
	72 Hours in air 21°C	0.0	0.0
	72 Hours in water 21°C	0.0	0.0
Formatray	1 Hour in air 21°C	0.2	0.0
	24 Hours in air 21°C	0.2	0.0
	24 Hours in water 21°C	0.2	0.0
	72 Hours in air 21°C	0.0	0.0
	72 Hours in water 21°C	0.0	0.0

0

4.5.3. Dimensional stability:

The results of the tests for dimensional stability are presented in Table 4-13. The warpage shown occurred during storage of the moulded baseplates in water at 37°C. At least ten tests were carried out for each material under each set of conditions.

TABLE 4-13.

DIMENSIONAL STABILITY.

Material	Warpage(mm) following storage in water at 37°C:	
	2 Hours	3 Days
Trayresin	0.60 ± 0.17	0.74 ± 0.20
Tray Plastic	0.30 ± 0.06	0.31 ± 0.04
Traybase	0.31 ± 0.09	0.38 ± 0.10
Formatray	0.45 ± 0.13	0.70 ± 0.20

4.5.4. Reproduction of surface detail:

In the preliminary experiments described in Section 4.1, tests were made of reproduction of surface detail. The results of these tests are given in Tables 4-1 and 4-2.

4.6. DISCUSSION.

4.6.1. Transverse strength and rigidity:

It can be seen from the graphs illustrated in Figures 4-9 to 4-33, that the cold-cured acrylic resin materials show plastic deformation whether tested in air at 21°C or in water at 37°C, but that the plastic deformation is greater for all materials at 37°C than at 21°C.

There was a wide range of transverse strength and stiffness amongst the four materials tested. There was also a wide range with any one material, depending on the conditions under which it was stored, and also the time between specimen preparation and the commencement of the test.

(a) The acrylic resin specimens prepared for comparison with the other materials varied in thickness from 2.1 mm to 2.6 mm, and thus variations in the results obtained could be attributed to some extent to this fact. The one hour tests indicated that all specimens tested in air at 21°C were stronger and more rigid than those tested in water at 37°C. Breaking loads could not be determined for Trayresin specimens

tested after one hour, at 37°C in water, since these specimens deflected for the full range of travel of the testing machine, without fracturing. All specimens tested after one hour were markedly weaker and less rigid than tests following a longer storage period.

Most of the results obtained were consistent in that specimens tested after storage under similar conditions were more rigid and stronger when tested in air at 21°C than in water at 37°C. The only exception was with Formatray specimens stored for 72 hours in water, in which case the specimens tested in air at 21°C were more rigid, but not as strong as those tested in water at 37°C. The difference in average fracture load of these Formatray specimens was only 0.1 kg.

For most materials, the results indicated that storage in air before testing resulted in stronger and more rigid baseplates than those stored in water before testing. However, this was not true of the Tray Plastic specimens, which were all stronger and more rigid when stored in water before testing. Another exception was with Trayresin specimens following storage for 72 hours, where, although specimens stored in air and tested in air were stronger than those stored in water, they were not as rigid.

Unexpectedly, an increase in the storage time of the baseplates was not always accompanied by an increase in strength

and rigidity; only with Trayresin and Formatray specimens was the fracture load greatest following storage for 72 hours. With Tray Plastic and Traybase materials, the strongest specimens were obtained after 24 hours' storage. The combination of greatest strength and rigidity was obtained with Formatray specimens tested in air, following storage for 72 hours in air, and Traybase specimens tested in air and stored in air for 24 hours. Tray Plastic specimens were the weakest tested in this group of materials.

(b) With specimens prepared to specification dimensions, width and thickness were constant, and for that reason, and the fact that specimens were smaller than the ones tested previously, there was no consistent correlation between the two sets of results.

Since specimens were of a uniform size, the results obtained under these conditions represent strength and rigidity of the materials themselves.

With specimens tested one hour after mixing the resin, those tested at 37°C in water were much weaker and less rigid than specimens tested in air at 21°C. With all materials except Traybase, the strength was greatest when the material was stored in air and tested in air at 21°C after 24 and 72 hours. With the Traybase specimens, strength was greatest following storage in water at 21°C and testing in air at 21°C.

Stiffness was greatest following storage in air also, except for Formatray specimens stored for 72 hours, which were stiffer when stored in water at 21°C than in air at 21°C.

For all tests at 37°C under water, the materials were stronger and stiffer after storage in air at 21°C than after storage in water at 21°C. All materials were stronger and stiffer when tested in air at 21°C, in comparison with specimens tested in water at 37°C, except for Tray Plastic specimens stored for 72 hours in water, where specimens tested at 37°C were stronger than similar specimens tested at 21°C in air.

With Traybase and Formatray materials, strength increased with storage time, but with Trayresin and Tray Plastic materials, strength was greatest after 24 hours' storage. The strongest material was Trayresin, closely followed by Traybase and then Formatray, whilst the material which showed greatest stiffness was Tray Plastic, although this was the weakest of the four materials. The specification transverse test carried out in water at 37°C, following storage for one week at 37°C, indicated that under these conditions the strongest and most rigid material was Trayresin. Tray Plastic was the weakest material, and was also the most flexible.

Apart from the exceptions mentioned, the strongest specimens were produced by storage in air, and strength increased with storage time. There was a marked reduction in

strength and rigidity when specimens were tested at 37°C in water, when compared with similar tests at 21°C in air.

It is interesting to observe in Table 4-10 that Formatray specimens prepared according to the proposed revision of B.S. 2847 for denture base resin (Section 4.2.1), were stronger and more flexible after 72 hours' storage than specimens prepared from the same material which had been allowed unconfined polymerisation.

4.6.2. Flow:

It can be seen from the results in Table 3-14 that the cold-cured acrylic resin materials did not exhibit a measurable flow when tested in air at room temperature, whatever the age of the specimens or the conditions of storage. In most cases measurable flow occurred when specimens were tested at 37°C in water. The amount of flow for any material was less than 1 per cent and was greatest, the shorter the time interval between mixing the resin and testing. The amount of free monomer in the resin decreases with time and there is a concomitant decrease in plasticity.

When tested at 37°C in water, all materials exhibited measurable flow after one hour, and all but Tray Plastic did so after 24 hours as well. However, Trayresin was the only material to flow after 72 hours' storage. The amount

of flow did not vary whether the specimens were stored in water or in air. Trayresin showed the greatest flow of the four materials, which confirms the results of the strength and rigidity tests, where Trayresin specimens generally showed the least rigidity and the greatest plastic deformation.

4.6.3. Dimensional stability:

It can be seen by comparing the results in Tables 4-12 and 4-13 that there is a definite correlation between dimensional stability and flow at 37°C in water. Tray Plastic showed least warpage and least flow, whilst Trayresin showed greatest warpage and greatest flow.

The mean warpage for all materials was greater after three days' storage in water at 37°C, than after two hours in water at 37°C, which could be attributed to the continued polymerisation of the resin being accompanied by a dimensional change. With Tray Plastic and Traybase baseplates, the increase in mean warpage between two hours' and three days' storage was not significant; Trayresin and Formatray baseplates showed an increase in mean warpage of 0.14 and 0.25 mm respectively. These results indicate that most warpage takes place within the initial two hour storage period following mixing the resin, and decreases with time.

An increase in storage time,up to 24 hours, is

accompanied by an increase in strength and rigidity of the materials also (Section 4.5.1). The low strength and rigidity after only one hour's storage and the high warpage of the materials after two hours, would contraindicate the use of the cold-cured acrylic resin materials in the preparation of a special tray for immediate use in impression procedures. Some authors[32,33] recommend the construction of an impression tray in cold-cured acrylic resin, in the mouth, for an immediate rubber base impression following inlay preparation. Successful crown and inlay restorations require the highest degree of accuracy during clinical and laboratory procedures, and the use of such a tray immediately after fabrication, when it is subject to measurable dimensional change and flow, and when its stiffness is at its lowest, is undesirable. The accuracy of rubber base impression materials is dependent upon the use of a rigid tray which is dimensionally stable. The majority of authors[34-39], however, recommend the preparation of a special tray on a preliminary gypsum cast, some time before taking the impression.

4.6.4. Reproduction of surface detail:

It can be seen from Table 4-1 that the time interval during which a material was sufficiently plastic to reproduce all the holes in the die was markedly different for each material. This qualitative test allowed an assessment of the

working time for each material, since the working time corresponded to the period during which the material was able to reproduce detail. In fact, these results agreed with the qualitative assessment of working time described in Section 4.1.3.

All the materials passed the qualitative test of reproduction of detail, and Trayresin, Tray Plastic and Traybase were sufficiently plastic to pass the test after five minutes from the onset of the doughing time. Formatray gave satisfactory reproduction for only 2.5 minutes, and it is doubtful whether this is long enough for adequate adaptation to a cast during baseplate formation. The prolonged working time demonstrated by Trayresin correlates with the results of the transverse deflection tests (Section 4.6.1) and flow tests (Section 4.6.2), where Trayresin specimens showed the greatest deflection and the greatest flow of the four materials.

The results of the packing properties test for reproduction of detail are presented in Table 4-2; only Trayresin and Tray Plastic passed the test. This indicated that the short periods over which Traybase and Formatray were plastic were inadequate to allow them to satisfy specification[12,13,14] requirements for packing properties.

CHAPTER 5

COMPARISON OF THE RESULTS.

5.1. INTRODUCTION.

Three different groups of materials have been studied: shellac, thermo-softening synthetic resins and cold-cured acrylic resins. Comparisons of different materials within each group have been made in the appropriate chapters. A comparison can now be made amongst materials from different groups.

5.2. COMPARISON.

5.2.1. Transverse strength and rigidity:

Due to the variation in thickness of the transverse strength specimens, it was possible only to compare the strength and rigidity of baseplates prepared from the respective materials, rather than the actual strength and rigidity of the materials themselves. The different materials within a group showed a variation in strength and rigidity and these differences were even greater when the groups themselves were compared.

The shellac specimens tested in air at 21°C showed a range of fracture loads of 1.8 to 3.3 kg, and deflections at fracture of 1.2 to 2.9 mm. When tested under water at 37°C,

fracture loads ranged from 1.4 to 2.5 kg, and deflections at fracture from 1.2 to 10.5 mm. The shellac specimens which showed greatest strength and rigidity were those prepared from Ash Metallized blanks, and these specimens were amongst the strongest and most rigid, both when tested in air at 21°C, and in water at 37°C.

Specimens prepared from the thermo-softening synthetic resin materials were not as strong and were far more flexible, as a group, when compared with shellac materials. They showed a range of fracture loads when tested at 21°C in air of 1.5 to 2.4 kg, and maximum deflections of 7.2 to 20.0 mm. When tested at 37°C in water, the fracture load varied from 1.0 to 2.4 kg and maximum deflections from 9.0 to 20.0 mm. The strongest specimens were prepared from Keba-Plast, both when tested at 21°C in air and at 37°C in water, whilst Bayer specimens were the most rigid when tested at 21°C in air. These specimens were neither as strong nor as rigid as the Ash Metallized specimens.

Specimens prepared from the cold-cured acrylic resin materials varied markedly in strength and rigidity, due to the fact that these materials are not preformed. Their strength increases for some time after initial hardening, due to continued polymerisation of the resin, with a resulting decrease in free monomer content, and therefore an increase in strength of the material. For this reason the fracture loads and

deflections at fracture varied widely depending on the time between preparing the specimens and testing.

When tested at 21°C in air, the fracture loads varied from 4.5 to 9.2 kg and deflections at fracture from 3.6 to 12.0 mm, whilst tests in water at 37°C resulted in fracture loads of 2.1 to 7.2 kg and deflections at fracture varied from 4.1 to 20.0 mm. All specimens prepared from the cold-cured acrylic resin materials were stronger than specimens of the preceding groups, even when tested one hour after mixing. This must be attributed, to some extent, to the fact that the acrylic resin specimens were thicker than specimens prepared from the preceding groups of materials. The acrylic resin specimens were as rigid as the shellac specimens, and more rigid than the thermo-softening synthetic resin specimens. The strongest and most rigid acrylic resin specimens were prepared from Formatray following 72 hours' storage in air before testing, and these were the strongest specimens of any material tested. They were also as rigid as the most rigid shellac specimens.

5.2.2. Flow:

Flow tests were carried out with the three groups of materials at 21°C in air and at 37°C in water, to determine the amount of flow that is likely to occur when these materials are used in practice. Flow tests were also carried out with the

shellac materials at 60, 70 and 80°C, since flow at high temperatures is indicative of the mouldability of the material. With the thermo-softening synthetic resins, flow of a similar magnitude would not occur at these temperatures, and in order to assess the mouldability of these materials, temperatures up to 180°C would be needed. It would be difficult to carry out flow tests satisfactorily at such temperatures, and these were not attempted. In the case of the cold-cured acrylic resin materials, the results of flow tests at temperatures above the softening temperature of the resins were of no practical significance, and again these tests were not attempted.

For the shellac materials, flow measured at 21°C in air was less than 0.1 per cent, whilst at 37°C in water the flow was less than 1.0 per cent. At 80°C all the shellac materials, except Alston Maroon, showed a flow of more than 90 per cent; in fact the Keur and Sneltjes materials showed a flow of 96 per cent when tested at 80°C in water, which was the highest for any shellac material at this temperature. This high flow agreed with the good reproduction of detail and ease in manipulation of these materials.

The thermo-softening synthetic resin materials did not demonstrate significant flow at 21°C in air or at 37°C in water.

The cold-cured acrylic resin specimens demonstrated a flow of less than 1.0 per cent. Flow was greatest one hour after mixing the monomer and polymer, and as the time after mixing increased, the measurable flow became less significant. These materials exhibited plastic deformation during transverse strength tests, and it was thought that this was likely to be a significant factor, superimposed upon stress relief, when these materials are used in practice. Trayresin specimens exhibited most flow of this group of materials and this agreed with the fact that transverse strength specimens of this material showed greatest plastic deformation.

5.2.3. Dimensional stability:

The warpage of shellac baseplates, after moulding, generally decreases as the softening temperature increases. The mean palatal warpage for all materials in the group following softening in water at 90°C, was of the order of 0.3 mm. Following softening in air at 90°C it was of the order of 0.2 mm. These warpages resulted from conditioning for two hours in a water bath at 37°C. Warpage could not be assessed after three days at 37°C (Section 2.2.3 page 23). The most dimensionally stable shellac baseplates gave a mean palatal warpage of 0.1 mm. This occurred with Ainsworth Aluminium following softening in water at 60°C, and also with Ash Pink, Ash Metallized, Cavex and Yellow-trays, when softened at 90°C

before moulding.

The thermo-softening synthetic resin materials showed a range of mean palatal warpage of 0.1 to 0.3 mm following two hours in water at 37°C, and after three days at this temperature the warpage varied from 0.1 to 0.9 mm. The most dimensionally stable baseplates were moulded from Keba-Plast, which gave a mean palatal warpage of 0.1 mm after two hours at 37°C, and this did not increase significantly after three days at this temperature. This material was in fact, the most dimensionally stable of all the materials tested.

The cold-cured acrylic resin materials showed a mean palatal warpage of the order of 0.4 mm after two hours in water at 37°C, and warpage of the order of 0.5 mm after three days' storage under the same conditions. All materials gave greater stress relief after three days' storage, although with Tray Plastic and Traybase baseplates, this increase was not great enough to be of practical importance. The most dimensionally stable cold-cured acrylic resin material, Tray Plastic, showed a warpage of 0.3 mm after two hours at 37°C and warpage of the same order after three days' storage. It can be seen that these materials are the least dimensionally stable of the three groups.

These results imply that baseplates which do not show a significant increase in warpage from two hours' storage at 37°C in water, to three days' storage under the same conditions,

have undergone almost all significant stress relief during the initial two hours' conditioning. Thus, they can be stored at room temperature for a prolonged period before use, without undergoing more warpage than this. Those materials stored in water at 37°C which showed a large difference between warpage measured after two hours and three days, should not be stored for any length of time before use, since stress relief, and thus warpage, would continue over a long period.

5.2.4. Reproduction of surface detail:

Some of the shellac materials passed the reproduction of surface detail test when softened at 60°C and all the materials passed the test when softened at 80°C. None of the thermo-softening synthetic resin materials passed the reproduction of surface detail test. These materials do not adapt intimately to a cast and thus do not reproduce its detail. This is confirmed when baseplates moulded from any of these materials are compared with a baseplate moulded from one of the better shellac materials (Figure 5-1). All the cold-cured acrylic resin materials passed the test, provided the test was carried out during the working period of the materials.

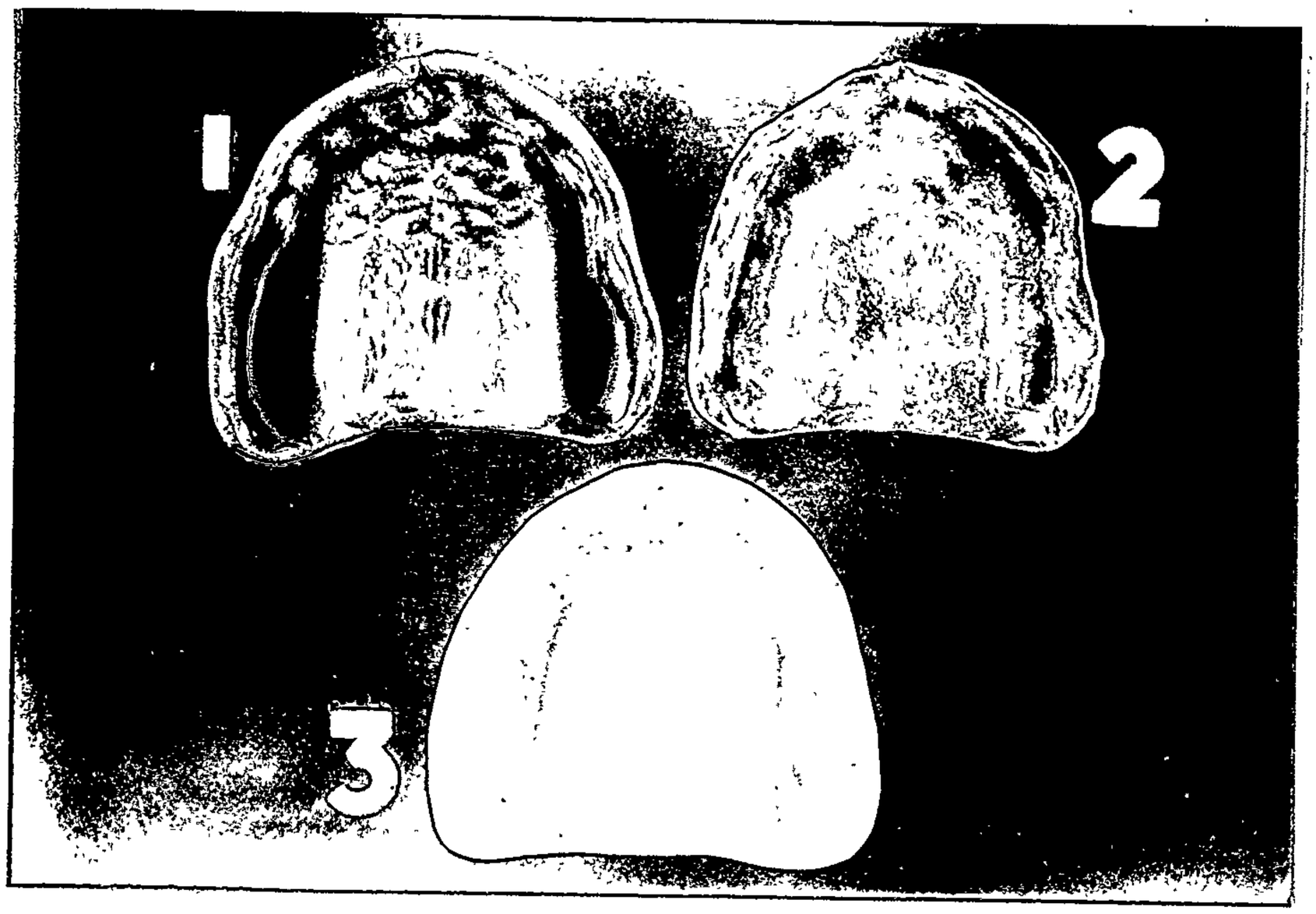


Figure 5-1

Baseplates of
1. Shellac;
2. Thermo-softening synthetic resin;
3. Cold-cured acrylic resin.

CHAPTER 6

CLINICAL SIGNIFICANCE.

6.1. INTRODUCTION.

Since the shellac materials showed the most satisfactory overall properties of the three groups of temporary baseplates assessed, it was decided to carry out supplementary tests, for this group of materials, in order to determine the clinical significance of the results obtained.

During dimensional stability tests, described in Section 2.4.3 (page 49), the conditions under which baseplates were prepared were ideal, in that they were uniformly softened, and maintained under uniform pressure while hardening. For this reason, the warpage due to stress relief should have been minimal. It was thus decided to study the relative warpage which would occur when baseplates were moulded under practical conditions.

For this purpose, baseplates were moulded by five dental technicians and were then subjected to the test for dimensional stability described in Section 2.4.3. Each technician moulded one baseplate from each material for each series of tests. Thus a comparison could be made with the results obtained in Section 2.5.3 (page 66). Three different shellac materials were selected, two which showed a large

amount of warpage (Ainsworth Brown and Alston Maroon), and one which showed a small amount of warpage (Yellow-trays) during preceding tests.

A second series of tests was then carried out to determine whether warpage was influenced (a) by embedding 0.06 inch diameter wire in the posterior section of the baseplate from one tuberosity region to the other. This is often employed in practice as an attempt to strengthen and stiffen baseplates; (b) by annealing the baseplate immediately after moulding, since it was thought that this might result in a release of the stresses induced during moulding, and thus minimise further warpage. Annealing was carried out by placing the baseplate, while seated on its cast, in an oven at 70°C for 20 minutes.

In order to determine whether heating the shellac materials at this temperature, for this length of time, would cause the material to flow under its own weight, measurements of thickness were taken with calipers before and after annealing. Thickness was measured at the periphery of the flange of the baseplate, and also along that section which covered the crest of the ridge of the cast upon which the baseplate was moulded. It was found that the thickness of the baseplate did not vary following the heat treatment, and thus baseplates were annealed in this way before being subjected to

the test for dimensional stability. The shellac material selected for these latter tests was one which had shown a large amount of palatal warpage during the preceding tests (Ainsworth Brown), so that variations in warpage would be more obvious than with one of the more dimensionally stable materials.

6.2. RESULTS.

The results of the tests are presented in Table 6-1. Each value is the mean of the results of five tests, and the standard deviations are given also.

TABLE 6-1.

Material Tested	Test	Warpage after 2 hours at 37°C in water.	Warpage after a further 1 week at 21°C in air.
Ainsworth Brown.	Moulded by dental	0.41 ± 0.20	0.50 ± 0.20
Alston Maroon.	technicians	0.08 ± 0.07	0.11 ± 0.08
Yellow-trays.	(no wire strengthener)	0.26 ± 0.01	0.30 ± 0.01
Ainsworth Brown.	Moulded by dental technicians and incorporating a wire strengthener.	0.45 ± 0.20	0.74 ± 0.20
Ainsworth Brown.	Moulded by dental technicians, annealed at 70°C for 20 minutes, and quenched to 21°C.	0.67 ± 0.20	1.00 ± 0.20
Ainsworth Brown.	Moulded by dental technicians, annealed at 70°C for 20 minutes, and allowed to cool to 21°C over one hour.	0.24 ± 0.04	0.41 ± 0.09

6.3. DISCUSSION.

For Ainsworth Brown and Yellow-trays, the warpage measured after two hours' heating in water at 37°C was about 0.4 and 0.3 mm respectively. These values fall within the ranges of warpage obtained for each material previously. This was to be expected, since baseplates were moulded following softening at 60, 70, 80 and 90°C in the original tests, and by heating a baseplate blank over a bunsen flame, temperatures within the range of 60 to 90°C could be expected.

Alston Maroon baseplates showed less warpage when moulded under practical conditions than previously. This could possibly be explained by the fact that the reheating of the material during moulding allowed moulding stresses to be released. Since this material is more difficult to mould than the Ainsworth and Keur and Sneltjes materials, a baseplate would take longer to make with this material, and thus heating over this longer period could allow the release of most of the moulding stresses before any measurements were taken.

It was interesting to observe that there was no significant increase in warpage for the three materials tested following subsequent storage at 21°C for one week. There was a range in the values of palatal warpage recorded for different baseplates within a group, but there was no correlation between any one technician and baseplates showing most warpage. It

appeared however, that those baseplates within a group which showed the smallest amount of warpage after two hours' heating in water at 37°C, also showed the smallest amount following a further one weeks' storage at 21°C in air.

The mean palatal warpage did not vary significantly whether or not a wire strengthener was incorporated in the baseplate. Thus, though a wire strengthener may prevent the posterior border of the baseplate from warping, it does not prevent overall warpage of the baseplate.

Annealing the baseplate immediately after moulding, and then quenching in water at 21°C, produced baseplates which showed excellent adaptation to the cast, but which then showed a relatively high warpage when they were subjected to the dimensional stability test (Figure 6-1). The palatal warpage measured after heating in water at 37°C for two hours was not significantly different from that recorded without annealing. It would appear that although annealing would have removed the stresses induced during moulding, further stresses were induced during quenching from 70°C to 21°C, due to restriction of the thermal contraction of the baseplate, by the gypsum cast.

This supposition was supported by the observation that when the annealed baseplate, on its cast, was allowed to cool slowly to 21°C, it still appeared to fit the cast very well. However, now palatal warpage, after two hours in water

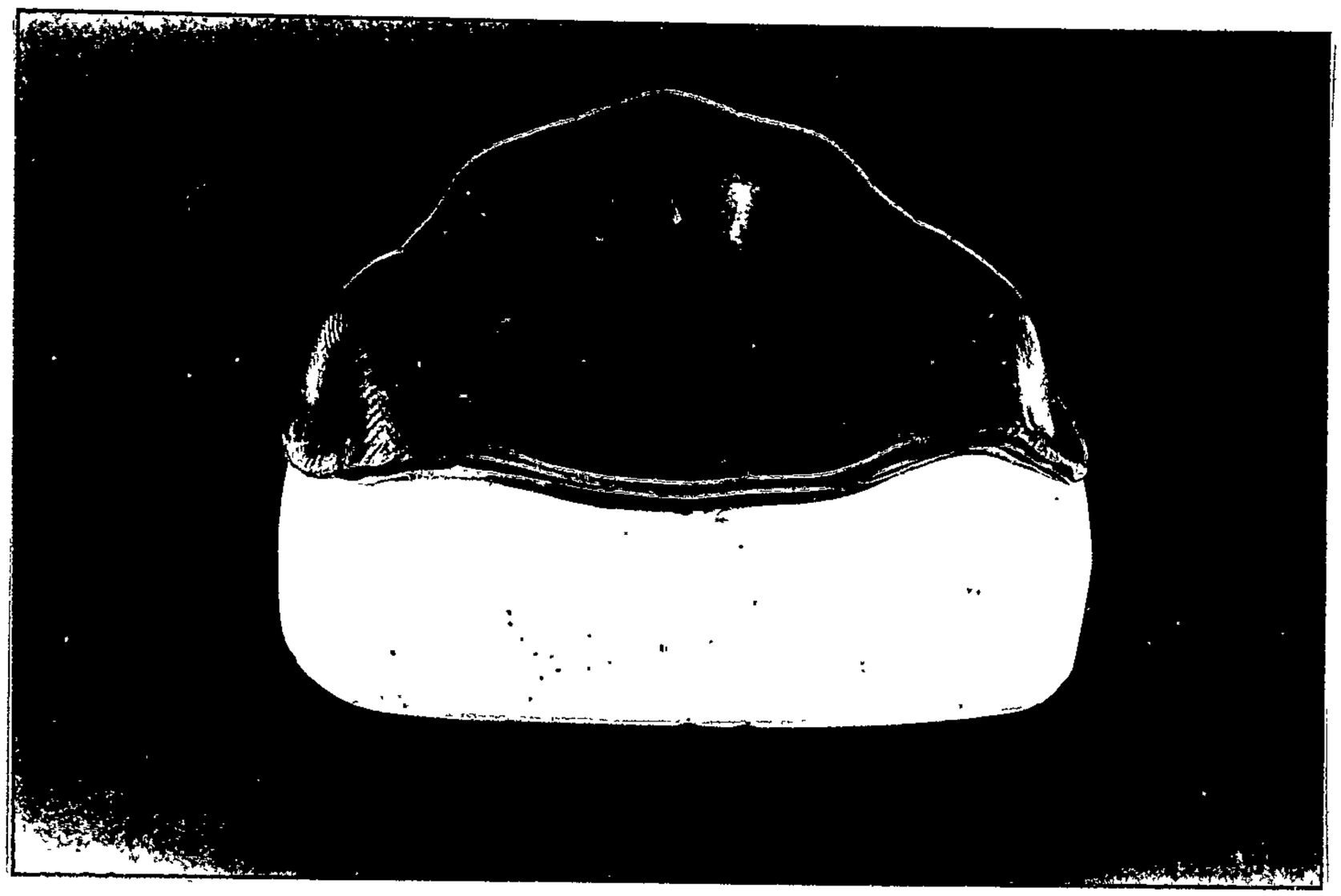


Figure 6-1

Warpage indicated by poor fit along the posterior border of the baseplate to the cast.

at 37°C, was reduced. It was significantly less than when the baseplates were cooled rapidly from 70°C after annealing, and also significantly less than the warpage measured on baseplates that were not annealed. It would appear that when the baseplates are allowed to cool slowly following annealing, the difference in thermal contraction between the shellac baseplate and the gypsum cast does not induce residual stresses to the same extent as when the baseplates are cooled rapidly. A reasonable explanation is that slow cooling allows time for relief of induced tensile stresses, by plastic deformation of the baseplate material. This would certainly happen quite quickly in the earlier stages of cooling, when the baseplate was still at temperatures at which flow was high.

It can be seen that by annealing a baseplate at 70°C in an oven for 20 minutes immediately after moulding, and then allowing the baseplate on its cast to cool slowly over one hour to 21°C, the subsequent warpage following two hours in water at 37°C is small. In fact the warpage measured following this method of manipulation was similar to the best results recorded for this material following ideal manipulation (Section 2.5.3 page 66). Following a further one week's storage at 21°C in air, the warpage was still relatively low.

CHAPTER 7

CONCLUSIONS.

From the comparisons in Chapter 5, it can be seen that the shellac materials, as a group, are stronger and more rigid than the thermo-softening synthetic resin materials; they are not as dimensionally stable as the latter materials, but the difference in mean palatal warpage is small. Moreover, the thermo-softening synthetic resin materials are very difficult to manipulate and show very poor reproduction of surface detail

The cold-cured acrylic resin materials are stronger than the shellac materials and as rigid. The fact that the cold-cured acrylic resin materials can be prepared to any desired thickness, with a resulting increase in strength, is an advantage. However, they are not as dimensionally stable as the shellac materials over a similar storage period, and though their reproduction of surface detail is good, when moulded during the dough stage, manipulation is more difficult and time-consuming when compared with the shellac materials.

Thus, it can be seen that although the shellac materials are not as strong as the cold-cured acrylic resin materials, nor as dimensionally stable as the thermo-softening synthetic resin materials, the best of them have properties which are more than adequate, and they have no serious disadvantages. It would appear then, that the shellac materials are the most satisfactory of the three different types of temporary baseplate materials tested.

REFERENCES

1. Yurkstas, A., and Kapur, K.K.. Factors influencing centric relation records in edentulous mouths.
J. Pros. Den., 14:6, 1054 - 1065 (Nov. - Dec.) 1964.

2. House, M.M.. Art-A fundamental in denture prosthesis.
J.A.D.A. and D.Cos., 24:407 - 422 (March) 1937.

3. Keyes, F.M.. Pitfalls in a full denture service.
J.A.D.A., 43:6, 651 - 663 (Dec.) 1951.

4. Zuckerman, A.. Baseplate stability.
Dental Survey, 37:5, 594 - 595 (May) 1961.

5. Wright, W.H.. Use of intra-oral jaw relation wax records in complete denture prosthesis.
J.A.D.A., 26:4, 542 - 557 (April) 1939.

6. Swensen, M.G.. Complete dentures.
St. Louis, Mosky Co., 3rd ed., 1953 (page 375).

7. Trapozzano, V.R.. A comparison of the equalisation of pressure by means of the central bearing point, and wax check bites.
J.A.D.A., 38:5, 586 - 591 (May) 1949.

8. Ringsdorf, W.M.. The ideal baseplate.
J.A.D.A., 50:1, 66 - 68 (Jan.) 1955.

9. Elder, S.T.. Stabilized baseplates.

J. Pros. Den., 5:2, 162 - 168 (March) 1955.

10. McCracken, W.. Auxiliary uses of cold-curing acrylic resins in Prosthetic Dentistry.

J.A.D.A., 47:3, 298 - 304 (Sept.) 1953.

11. Terry, J.M., and Wahlberg, R.. Vacuum adaptation of baseplate materials. A report prepared in the Dental Sciences division of the American Air Force. June 1964.

12. American Dental Association. A.D.A. Specification No. 12, Denture base resins, 1953.

13. British Standards Institute. British Standard B.S. 2847, Non-metallic denture base material, 1954.

14. Standards Association of Australia. Australian Standard T.11, Acrylic denture base resin, 1959.

15. U.S. Government. Federal Specification CG-B-120a, Dental baseplate, 1956.

16. Sweeney, W.T., Caul, H.J., and Gresig, W.. A transverse testing machine for denture resins.

J.A.D.A., 49:2, 174 - 176 (August) 1954.

17. Skinner, E.W., and Phillips, R.W.. The science of dental materials. Philadelphia, W.B. Saunders Co., 5th ed., 1963 (page 21).

18. American Dental Association. A.D.A. Specification No. 3, Dental impression compound, 1955.

19. Standards Association of Australia. Australian Standard T.6, Dental modelling compound, 1956.

20. American Dental Association. A.D.A. Specification No. 4, Dental inlay casting wax, 1941.

21. Standards Association of Australia. Australian Standard T.14, Dental inlay casting wax, 1956.

22. Standards Association of Australia. Australian Standard T.17, Dental modelling wax, 1961.

23. Katay, P.. Personal communication, 1964.

24. Bevan, E.M., and Smith, D.C.. The properties of impression compound.
Brit. Dent. J., 114:5, 181 - 185 (March) 1963.

25. Connors, F.L. Personal communication, 1965.

26. Skinner, E.W., and Phillips, R.W.. The science of dental materials. Philadelphia, W.B. Saunders Co., 5th ed., 1963 (page 208).

27. Harman, I.M.. Effects of time and temperature on polymerisation of a methacrylate resin denture base.
J.A.D.A., 38:2, 188 - 203 (Feb.) 1949.

28. Wolcott, R.B., Paffenbarger, G.C., and Schoonouer, I.C.. Direct resinous filling materials: temperature rise during polymerisation.
J.A.D.A., 42:3, 253 - 263 (March) 1951.

29. Skinner, E.W., and Phillips, R.W.. The science of dental materials. Philadelphia, W.B. Saunders Co., 5th ed., 1963 (page 193).

30. Swaney, A.C., Paffenbarger G.C., Caul, H.J., and Sweeney W.T.. American Dental Association Specification No. 12 for denture base resin; second revision.
J.A.D.A., 46:1, 54 - 66 (Jan.) 1953.

31. British Standards Institute. Draft revision of British Standard B.S. 2847, Non-metallic denture base material, 1965.

32. Davis, M.C.. The use of rubber base impression materials in the construction of inlays.
J. Pros. Den., 8:1, 123 - 134 (Jan.) 1958.

33. Ingraham, R.. Acrylic tray technique.
J.A.D.A., 71:1, 18 (July) 1965.

34. Shippee, R.W.. Accuracy of impressions made with elastic impression materials.
J. Pros. Den., 10:2, 381 - 386 (March - April) 1960.

35. Woelfel, J.B., and Paffenbarger, G.C.. Stability of plastic impression trays.
J.A.D.A., 63:5, 705 - 706 (Nov.) 1961.

36. Pickard, H.M.. Impression materials and methods in crown and bridge prosthesis.
Int. Den. J., 8:2, 355 - 356 (June) 1958.

37. Johnson, J.F., Phillips, R.W., and Dykema, R.W.. Modern practice in crown and bridge prosthodontics. Philadelphia, W.B. Saunders Co., 1960 (page 202).

38. Skinner, E.W., and Phillips, R.W.. The science of dental materials. Philadelphia, W.B. Saunders Co., 5th ed., 1963 (page 127).

39. Bailey, L.R.. Acrylic resin tray for rubber base impression materials.
J. Pros. Den., 5:5, 658 - 662 (Sept.) 1955.

QUEEN'S UNIVERSITY DENTISTRY LIBRARY