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A Study of Visco-Elastic Properties of Denture Liners and Classification of Terminology

by

John Anthony Churchin, BDS

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Department of Prosthetic Dentistry
Faculty of Dentistry
The University of Sydney

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Declaration

This is to certify that the work presented in this thesis was carried out by the candidate in the Faculty of Dentistry, University of Sydney, and has not been submitted to any other university or institution for a higher degree.

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Abstract

Denture liners display varying rheological behaviours ranging from the almost completely elastic Molloplast B (MB) to the viscoelastic Visco-gel (VG). Because of these differences and the non-existence of international standards, confusion exists in the literature terminology with the phrases, resilient and soft being used interchangeably. The aim of the present study was to develop a protocol for the rheological testing of denture lining materials that would help solve this confusion. The apparatus and procedure attempted to utilise both the dynamic and compressive creep elements of previous studies. Specimens of MB (a heat and pressure cured silicone) and VG (a self-curing tissue conditioner or polymer/gel) were tested under the simulated oral conditions of 37^0C in a water bath. Five specimens of each material were tested under three different loads: 100g, 200g and 400g. One specimen served as a control. The thickness and weight changes and the rheological characteristics of both materials were compared at 1hr then once a day for 6 days followed by once a week for six weeks. Initial loading of VG (200g) resulted in (R_1) 44.32±14.5% recovery and after 15 compression cycles (R_2) 13.43±5.19%. At 6 wks it was 40.41±13.07% and 12.13±9.54% respectively. MB was (R) 78.88±20.63% and 84.48±3.28% respectively. Permanent deformation for VG:at 1 hr 5.40±0.98%, at 6 wks 5.72±2.06% and for MB: at 1 hr 1.48±1.84% and at 6 wks 1.14±0.16%. The performance of VG was more consistent than MB and t tests of E over 6 wks showed no significant differences ($p>0.05$) but significant differences for MB ($p>0.05$). We conclude that specimens of liners should be >10cm^2, should be 3mm thick to simulate the clinical state, should have a surface separating medium, should be tested in a heated water bath and be loaded cyclically with the optimum load of 200g.

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CHAPTER 1

LITERATURE REVIEW

1.1 Introduction

One of the main causes of resorption of denture supporting structures is traumatic force transmitted through a prosthesis (Atwood 1971; Whinery 1975). A combination of systemic and/or local factors may give rise to either a reduction in the capacity of the denture bearing area to support normal forces or an increased force on supporting tissues due to changes in occlusal load distribution (Franks and Hedegard 1973; Qudah et al. 1990). In an attempt to overcome pain, trauma and resorption arising from these changes, it is necessary both to reduce and evenly distribute the load transmitted by the dentures. In the past extensive use has been made of denture lining materials for this purpose.

In spite of extensive investigation of denture liners for reaction with cleansers, surface texture, reproduction of detail, frictional characteristics, adhesion to acrylic resin, water sorption, hardness, and compression set and strain (Bates and Smith 1965; Wright 1976; Wright et al. 1985; Suchatlampong 1986; Kazanji 1986 and Davenport 1986), there exists at present no internationally accepted standards by which these materials may be chosen, compared or evaluated (Mack 1989).

Clinicians are therefore presented with a dilemma as to what parameters to use in selecting a lining material.

Various authors (Robinson and McCabe 1982; Newsome et al. 1986; Katakura et al. 1989; Murata et al. 1990) point to the property of viscoelasticity as being important since this enables the material to exert a cushioning effect on the oral tissues and to change shape during function. Work by Thomas and Mori (1990) has shown that Molloplast B, the popular liner behaves in a totally elastic fashion (similar to elastomeric impression materials) and therefore does not conform to tissue changes over time. This study is an extension of this work and includes a new testing method developed to examine critically the rheological properties of lining materials.

1.2 Physical changes of the mandible on tooth loss

During a lifetime human tissues undergo anabolic and then catabolic changes (Lammie 1956). The oral tissues, both hard and soft are also subjected to these processes and when teeth are lost the implications for denture wearing are much more favourable during the anabolic than the catabolic phase.

The mucosa and submucosa in common with all other tissues show a reduction in the number of their component cells as ageing and atrophy take place. The mucosa covering the mandibular ridge in particular shows a decrease in thickness. There is also an associated atrophy of the submucosa. This change is partly explained by a general dehydration which is observed in old age (Lammie 1956). Pendleton (1951) gave a detailed histological description of the mucosa which covers the edentulous bone. He found parakeratosis and acanthosis in the

epithelium of edentulous ridges which had never supported a denture. The shape of the basement membrane was irregular rather than sinusoidal, and the lamina propria and submucosa showed a slight infiltration of round cells without clear evidence of inflammation. The connective tissue was found to be particularly tolerant to masticatory stresses.

The wearing of a denture introduces mechanical, chemical and thermal factors, each of which may contribute to ageing changes (Turk 1965). Ostlund (1958) showed that within six months the epithelium of most patients with a complete denture showed a pronounced change despite the clinically normal appearance of the mucosa. The changes progressed in a typical way:

(a) Stratum corneum decreases in thickness with simultaneous thinning of the stratum granulosum.

(b) All keratin disappears from the epithelial layer and the cells of stratum spinosum change in appearance.

(c) During the initial stages of the tissue changes the number of mitoses increases, probably to compensate for the increased strain placed on the surface epithelium by the wearing of the denture. If however the injury is more advanced, the number of mitoses decreases.

(d) The connective tissue becomes oedematous as the connective tissue papillae are gradually pressed up towards the surface of the epithelium.

(e) The increase observed in the epithelium is partly due to an increase in volume of individual cells and partly due to oedema of the tissues.

Turck (1965), in a similar study described the various

histological states of the mucosa of edentulous denture and non-denture bearing regions and related them to age. He came to the conclusion that tissue changes in the mucosa covering the edentulous ridges , with or without dentures can be considered as adaptation to abnormal conditions. He sees the changes as being akin to age changes, ie. both are adaptations to changing conditions. It was only when conditions were beyond the physiological tolerance of the tissues such as those created by ill-fitting dentures or decreased tissue tolerance that an abnormal reaction of the tissues resulted. It is in these circumstances that a denture liner becomes beneficial.

Carlsson and Persson (1967) conducted a five year study of the changes of alveolar ridges occurring in the mandible after loss of teeth and found that the height of the mandible in the incisor region decreased by about 2mm in the first two months. The mean reduction after 1 year was between 4 and 5 mm and at 5 years about 7 mm. The range for the series was extremely wide.The loss of height of the mandible was greatest in the incisor region and least in the molar region. They also found that the reduction in the width of the alveolar process during the first two months was on average 2 mm, then 3 mm in the first year and insignificant thereafter.

Examination of the edentulous mandibular ridge reveals that cortical bone is often absent from the anterior segment of the residual ridge after healing of the extraction wounds. The ridge crest is in fact formed by cancellous bone (Lammie 1956). Atkinson and Woodhead (1958) found that once the mandible had reached maturity, the resorption which contributed to the remodelling of the

jaw during growth continued and became more extensive with ageing. Such resorption not only leads to an uneven distribution of porosity within the bone but also results in the changes of shape typical of the edentulous senile mandible.

This resorptive process is a complex biophysical phenomenon that Atwood (1962) broke down into four categories;

1.) Anatomic factors.

Included here are the amount and the quality of bone.

2.) Metabolic factors.

This will be a function of:

a. basic anabolic/catabolic processes,

b. hormonal interplay, eg menopause,

c. dietary factors,

d. pathologic conditions, eg osteoporosis and periodontal disease (Ortman 1962; Whinery 1975; Wendt 1974).

3.) Functional factors.

When force within certain physiological limits is applied to living bone, that force, whether compressive, tensile or shear, brings about remodelling of the bone. The functional factors of frequency, intensity, duration and direction of force are translated into biological cell activity. After the loss of the natural teeth the bone cannot be stimulated by a denture base as the teeth did internally. A decrease in the force of occlusion develops because the mucous membrane and periosteum cannot endure

the force once received by the teeth. This loss of internal stimuli and the reduction of closing force are signals for disuse atrophy and a remodelling of the bone. Disuse atrophy does not result from the direct loss of non-functional bone, but rather from the lack of replacement of bone not needed for function. The denture base does give some stimulus, but it is an unnatural stimulus (Lammie 1956; Ortman 1962; Wendt 1974; Whinery 1975).

4.) Prosthetic factors.

Available evidence is inconclusive and seems to indicate that a denture base may act either to retard or hasten the process of bone resorption. The prosthetic factors are extremely difficult to evaluate because of the tremendous number of variables including the anatomic, metabolic and functional factors already mentioned (Ortman 1962).

Fundamentally however, the wearing of a denture is physiologically incompatable with the function of the ridge tissue, and the undesirable fact is that the denture base applies direct pressure upon bone through vascular tissue. It is here that a denture liner may be effective in reducing this pressure.

No matter what the cause is, there will be a gradual change in the shape of the denture bearing area over time. The majority of people adapt to these changes by alteration of masticatory habits or neuromuscular control. Those unable to adapt present with complaints ranging from instability of their dentures, occlusal prematurities and constant pain on eating, to poor esthetics and difficulties with speech. Whatever the symptoms may be the

one certain fact is that resorption of the residual alveolar ridge represents a major problem to denture wearers and the dentist.

1.3 Means of countering mandibular denture problems

Watt (1976) found that when a tooth is lost the periodontal area that supported the masticatory load on the tooth is also lost, and in its place there remains a small area of mucosa equivalent to the cross-sectional area of the neck of the lost tooth. This represents both a qualitative (unlike the periodontium the mucosa is not a specialised supporting tissue) and a quantitative problem as the periodontal area of the lost tooth is approximately four times that of the mucosal area. Based on this fact and the conditions mentioned previously (Section 1.2), there is a need to devise some means of either decreasing the force applied to the ridge or utilising as much of the available supporting area as possible.

In order to maximise the supporting area the tissues should be in a state of health before impressions are made. Lytle (1959) gives the following justification for allowing soft tissue recovery prior to the making of a new denture: a satisfactory impression for the construction of a new denture cannot be made of an abused ridge and maxillo-mandibular relations made on deformed tissues perpetuate occlusal errors in the new denture. He recommends the following procedures to return the traumatised and deformed soft tissues to a healthy form:

(a) dentures are left out over night,

(b) the tissue surfaces of the denture are corrected by

relieving all areas causing excessive pressure,

(c) any extended denture borders are shortened,

(d) temporary treatment relining material is placed in the dentures if they are not stable,

(e) a soft diet and tissue massage are prescribed.

It may not be possible to return the soft tissues to a state of complete health, but once the stage is reached where the patient is reasonably comfortable it is then important to construct a denture that replaces the lost tissues in approximately the same amounts and in the same positions from which the tissues were lost (Pound 1957). By following this treatment path there will be not just an increase in support but also in retention and stability of the lower denture (Watt 1976; Osborne 1960). As a consequence of this there should be a decrease in the force acting on the residual ridge.

Fish (1952) proposed the concept of the three denture surfaces i.e. polished, occlusal and fitting. The attributes of each surface needs to be optimised to ensure denture success.

The polished surface of a lower denture extends from the periphery up to but not including the occlusal surface of the teeth. To ensure stability it is essential that this surface conforms to the musculature since this is the major destabilising force. Lammie (1956) stressed the importance of an understanding of the resting, functional, compressed and distorted positions of the mucosal reflection for developing the best retention and fit in the complete lower denture. Over extension can lead to localised areas of mucosal ulceration or inflammation. while under extension decreases the surface area available

to dissipate the functional load. Once the various positions and heights of muscle attachments are known the teeth can be placed in a " neutral zone " of muscle activity (Pound 1956). Brill et al. (1965) categorize the musculature into dislocating and fixing muscles, the actions of which make the denture space a dynamic entity. Being enclosed by the buccinator and mentalis buccally and the tongue lingually, some authors (Lammie 1956; Lytle 1959; Osborne 1960) advocate the use of narrow posterior teeth to allow maximum tongue space and to increase the possibility of facial seal being developed buccally.

Lytle (1959) states that deformation of underlying soft tissues tends to disguise occlusal errors and makes it mandatory that all occlusal discrepancies are eliminated before the patient wears the dentures. The teeth should be placed where the muscles and mucosa will allow and not in a position to develop any idealistic concept of occlusion (Lammie 1956). The occlusal form from the commencement to completion of treatment should harmonise with the learned functional muscle patterns contained in the mesencephalic nucleus. This means that bases and wax rims should also approach the expected occlusal pattern so that no errors in recording procedures happen (Osborne 1960). The vertical dimension is also important so as not to cause excessive pressures on the supporting structures when the teeth come into contact (Wendt 1974). Where there is inadequate free-way space a true resting position of the mandible is never attainable. This results in a continuous load to both jaws.

It is also important that there is freedom and balance in lateral, protrusive and retrusive movements so as not

to cause excessive lateral or posterior-anterior forces on the ridge (Osborne 1960). Klein and Miglino (1966) found in a study of the use of tissue conditioning materials that correction of dentures was a key to favourable results. The problems that they were endeavouring to correct included excess of vertical dimension, over-relief of the denture, underextended borders, incorrect maxillo-mandibular relation and general occlusal imbalance. Even in a situation where there is a perfectly balanced occlusion, there still may be parafunctional habits such as bruxism (Whinery 1975) which are placing undue stresses on the supporting tissues. In these situations it may be worthwhile to recommend some psychotherapy or counselling to try to reduce the extent of the problem.

The fitting surface of a denture affects the form of the underlying soft tissues. Lytle (1959) recommends the use of a normal plastic base but warns of; constructing dentures over unhealed sockets, the arbitary placement of relief areas which compromise adaptation and support and the dimensional changes associated with plastic bases which can affect fit.

Lammie (1956) recommends the development of an adequate soft denture base. Compression of a denture liner leads to absorbtion of some energy and assists in the even distribution of force over the spicular bone and atrophied mucosa. Osborne (1960) recommends using the existing lower denture base but replacing the tissue fitting surface in certain situations, especially where the only complaint is slight movement. A new denture made from an accurate impression of the whole of the residual ridge area will distribute the masticatory force to tissues that have not

been loaded for a long time. Very often they are unable to accept the load and pain is the result. He also stressed the need to remove any minute imperfections following processing, the presence of which can cause chronic irritation of the mucosa.

In some cases the aforementioned prosthetic procedures may not be adequate to correct the resorptive process and its associated problems. This is especially true in the following situations where alternate methods would be needed to achieve satisfactory results:

(a) Abnormalities of soft tissues.

As age atrophy progresses (Lammie 1956), the oral epithelium shows a reduction in the number of cells and in the elasticity of the collagenous supporting structure. Another problem is that of replacement of the alveolar bone by fibrous tissue. This leads to distortion and pain under the functional load of the denture. A related problem is that of exposure and pressure on peripheral nerve endings. Movements of the denture tend to impinge on these structures resulting in "trigger spots" causing intermittent pain.

(b) Abnormalities of bone.

The remaining crest of alveolar bone may have been reduced to a series of sharp and irregular spicules and pressure applied by the denture certainly causes pain. Furthermore general bone loss may lead to muscle attachment areas such as the mylo-hyoid and genial tubercles becoming prominent.

In both soft and hard tissue abnormalities there are two treatment alternatives. Firstly, surgical removal and secondly, the use of a denture liner.

1.4 Terminology of Denture Liners

Since Twitchell first wrote about the use of denture liners in 1869 (Qudah et al. 1990) they have been used in many conditions and forms. Most authors have categorised the materials into either resilient liners (Lammie 1958; Travaglini et al. 1960; Craig and Gibbons 1961; Eick et al. 1962; Storer 1962; Bates and Smith 1965; Gonzalez 1966; Ortman 1966; Laney 1970; Gonzalez 1977; Bell et al. 1977; Burns et al. 1987; Khan et al. 1989; Graham et al. 1990; Graham et al. 1991), or soft liners (Matthews 1945; Wilson et al. 1969; Wilson and Tomlin 1969; Braden and Clarke 1972; McCabe 1976; Wright 1976; Duran et al. 1979; Ellis et al. 1979; Wright 1980; Ellis et al. 1980; Harrison 1981; Wright 1981; Robinson and McCabe 1982; Wright 1982; Braden and Wright 1983; Gettleman et al. 1983; Goll et al. 1983; Wright 1984; Wright et al. 1985; Davenport et al. 1986; Davis and Carmichael 1988; Kazanji and Watkinson 1988; Newsome et al. 1988; Kalachandra and Turner 1989; Mack 1989; Graham et al. 1990; Murata et al. 1990). Suchatlampong et al. (1986) actually use both terms interchangeably throughout their article.

A review of the definitions will show that in actual fact the phrases resilient and soft are not interchangeable. Boucher's glossary of Current Clinical Dental Terminology defines resilience as the energy absorbed owing to elastic deformation (Laney 1970). In mechanical terms it is measured by the area under the elastic portion of the stress-strain curve and indicates the amount of energy necessary to deform the material to the proportional limit (Craig 1985). This is a restrictive term that fails from both a rheological perspective to

take into consideration the viscous flow of the liners, and from a purely descriptive perspective to describe the general quality of the materials. This point is very important to the layman who wants a term that is simple and descriptive. This is where the adjective "soft" is very useful for describing the liners. The term has no scientific significance and Steadman's Medical Dictionary (1942) defines soft as "not hard, not resistant, yielding". It is therefore purely a descriptive term.

It appears that a prolonged service life is important when the term "resilient" is used for denture liners. In fact, Ellis et al. (1980) make the statement that the term "resilient" is actually a misnomer and that denture liners need to be categorised on the basis of time in use. They regard liners as either temporary or semipermanent. This system of differentiation is also not without its problems with the distinction between the two being purely arbitrary.

Tissue conditioners used for a short period help to condition hypertrophic, irritated and displaced tissue to a healthy state prior to construction of a new denture (Gonzalez 1977; McCarthy 1984). Liners are used over a longer term and are a part of the denture base itself. They are useful in patients with resorbed or atrophic ridges where bony or soft tissue irregularities are present but surgery is contraindicated (Gonzalez 1977; Mack 1989; Qudah et al. 1990). It would be convenient if there was a material that performed over both the long and short terms. Harris (1961) stated " if there were a material for cushioning dentures that would retain soft, compatible properties for as long as one year, most of the

chronic complaints in denture service would be eliminated.

1.5 Properties of tissue conditioners and denture liners

1.5.1 Tissue conditioners

Since the first serious work on liners by Matthews (1945) the search has been on for a material which produces an even distribution of functional load over the entire denture bearing area thereby permitting the deformed mucosal tissues to return to their normal position (Wilson et al. 1969; Duran et al. 1979). They may be used to treat hyperemic and traumatised oral mucosa, papillary hyperplasia, denture stomatitis, poorly occluding dentures and bruxism (Gonzalez 1977; Harrison 1981).

Tissue conditioners are usually polymer gel systems based on a poly(ethyl/methyl methacrylate) copolymer (Braden 1970a; Brooks and Bates 1985). Visco-gel (De Trey) is one of the most commonly used tissue conditioners. Jones et al. (1991b) analysed a sample of Visco-gel by pyrolysis/gas chromotography and found that the composition was 14.5 per-cent methyl methacrylate and 85 per-cent ethyl methacrylate. Further analysis of second and third lots gave inconsistencies in this ratio, thereby implying that the chemical composition of Visco-gel may not be consistent from one lot to the next.

The polymer beads are combined with an ester plasticiser and ethanol, which acts as a swelling agent (Wilson et al. 1966; McCabe 1976; Gonzalez 1977; Wright 1981; Parker and Braden 1982; Jones et al. 1988, 1991a). The mechanism for setting is primarily physical in nature.

The alcohol/plasticiser solution mixed with the powder initially produces a slurry which becomes stiffer as the liquid penetrates the powder particles. The more alcohol present the deeper and more rapid will be this penetration, resulting in a shorter setting time and a harder product (Wilson et al. 1966). The materials are usually blended to undergo gelation in the mouth when mixed with, typically, between 80 and 95 per cent plasticiser and a balance of ethyl alcohol (Jones et al. 1991b). It is desirable however to reduce the alcohol content because the taste and sensation of ethanol are objectionable to many patients, and also the ethanol is easily leached out in the mouth contributing to hardening of the material (Braden 1970b).

As this material is primarily a solid/liquid solution (a gel) it should exhibit plastic characteristics provided there are no environmental interactions. It has been demonstrated that intraorally these plastic properties are gradually lost and the material exhibits a more elastic nature. This is due to a threefold sequence of events consisting of ethanol loss, water absorption and loss of plasticiser.

The loss of ethanol commences immediately after the material is immersed in an aqueous medium. Two-thirds diffuses out by a certain process relatively rapidly (within 10 hours at 37^{0}C), while about one-third diffuses out by another process taking about two years to complete (Ellis et al. 1979). The degree of water absorption is dependent upon the chemical composition of the polymer and the proportion of polymer in the gel. The equilibrium

water uptake (balance between the uptake and loss of water by natural diffusion processes) is a function of the surface area and thickness of the specimen and is slightly temperature dependent, while the rate of water uptake and the time taken to reach equilibrium is highly temperature dependent and governed by diffusion coefficients (Braden and Wright 1983).

For regular unmodified dental polymers the determination of diffusion coefficients in absorption and desorption at 37^0C and of the equilibrium uptake are relatively easy. Any additive such as a plasticiser will significantly change the water absorption behaviour (Braden and Wright 1983). When immersed in water the plasticisers leach out of the material thereby affecting the dimensional stability and compliance. They also reduce the water absorption by filling the microvoids in the material which in the absence of such additives can accommodate water (Kalachander and Turner 1989).

The net result of ethanol loss and water absorption is usually a weight loss as the lighter water molecule replaces the heavier ethanol molecule. It has been assumed that such weight loss would result in a volumetric change (Braden and Causton 1971). McCarthy and Moser (1978a) do not see this necessarily as a valid assumption. They state that if the material is left in situ until an equilibrium has been established the initial weight loss (with or without significant volumetric change) can be accommodated by the plasticity of the material.

Since the ethanol loss and water absorption do not occur at the same rate with ethanol loss being initially

faster (Braden and Causton 1971; Ellis et al.1977), the physical properties of the set material should vary. Initially an increasing hardness occurs as ethanol loss exceeds water absorption (Duran et al. 1979; Ellis et al.1980). This is then followed by a degree of softening as water absorption increases. This increase in softness is relative to the increased hardness from the first phase of ethanol loss. In time hardening continues progressively as water uptake reaches an equilibrium, while ethanol and eventually plasticiser are continually being leached into the saliva. while the water has some softening qualities it is less effective as a plasticiser than the chemicals chosen for this purpose (Braden and Wright 1983).

For Visco-gel the differences found by Jones et al (1991b) in methyl methacrylate/ethyl methacrylate ratios can have a large bearing on the aforementioned processes. The cohesive energy parameter of poly(ethyl methacrylate) is closer to that of ethyl alcohol than is that of poly(methyl methacrylate), and therefore it would seem that poly(ethyl methacrylate) should undergo gelation in the presence of a plasticiser/alcohol liquid mixture more readily than would poly(methyl methacrylate). The higher surface energy and lower glass transition temperature of poly(ethyl methacrylate) in comparison with those of poly(methyl methacrylate) should allow an effective soft polymer system to be formed. In fact poly(ethyl methacrylate) may also be the highest methacrylate that can be used to produce a reasonably free-running polymer powder (Jones et al. 1991b). Therefore any change to the ethyl/methyl ratio may have a large bearing on the

properties of the material.

Both the mixing procedure and the powder/liquid ratio will have a bearing on the aforementioned processes. McCarthy and Moser (1978a) state that the actual proportions are not considered critical, and that in the literature supplied with their materials many manufacturers state that the liquid/powder ratio can be varied to suit the clinicians needs. In clinical use however dentists generally mix Visco-gel to a consistency that they feel confident with and ignore recommended mixing instructions. But for the sake of conformity and comparison it is important to follow manufacturer's directions when preparing the samples (Wilson et al. 1969). Weighing reduces errors inherent in the volumetric method normally used (Ellis et al. 1980).

1.5.2 Denture liners

1.5.2.1 The silicones

The commercially available denture liners generally fall into two basic groups, the silicones and the acrylics. The silicone materials are similar in composition to dental silicone impression materials (Braden 1966) and are basically polymers of dimethylsiloxane. Poly (dimethylsiloxane) is a viscous liquid which can be cross-linked to give good elastic properties. The cross-linking agent is normally an alkyl silicate and the reaction is usually catalysed by an organo-metal salt such as tin-octoate. At mouth temperature silicone rubber is approximately 160^{0}C above its glass transition temperature(Tg). Below this

temperature the polymers are rigid and above it they behave like a rubber. It is possible to lower this temperature by adding chemicals called plasticisers thereby making the material plastic at mouth temperature (Brown 1988). The flow property can also be controlled by the degree of cross-linking (McCabe 1976). The two commonly available types of silicone liners are Molloplast B (Kostner and Co, Germany), a heat polymerising material supplied as a one paste system, and Flexibase (Flexico Development Ltd, London), a paste and liquid system (Qudah et al. 1990).

1.5.2.2 The acrylic resins

Both heat-cured and autopolymerising acrylic resin materials are used for denture lining. They consist of powder and liquid components but chemical compositions of these components are not well documented due to a failure of most manufacturers to disclose them (Ellis 1979).

They are usually composed of a powder of poly (ethylmethacrylate) and a liquid of any of a range of higher methacrylates (e.g. n-butyl, 2-ethoxyethyl methacrylate, laural methacrylate), with a phthalate plasticiser. The plasticiser lowers the Tg of the polymer thereby reducing the modulus of elasticity to a satisfactory level. Dibutyl phthalate is no longer used as a plasticiser because of the toxic effects of the phthalic acid which is formed by hydrolysis in the stomach (Ellis 1979). Another method to produce softness is to add an extra catalyst or transfer agent to the monomer which then decreases the molecular weight of the polymer. A more common procedure is the use of ethyl or butyl methacrylate in combination with methyl methacrylate to produce a

copolymer (Travaglini et al. 1960). Ethanol may be added to the plasticiser to increase the rate of diffusion of the plasticiser into the polymer beads (Ellis et al. 1980).

1.6 Uses of denture liners

Liners are usually part of the denture base itself and used for longer time periods than the tissue conditioners. They have been used in the following situations;

(a) Aging and pathological changes.

The liner replaces the missing resilient tissue layer covering the residual ridge. This allows an equalisation of the pressures of mastication (Lammie and Storer 1958; Storer 1962; Gonzalez and Laney 1966; Laney 1970; Gonzalez 1977; Mack 1989; Qudah et al. 1990).

(b) Local relief of pressure.

Bony contours such as the mylohyoid ridge, genial tubercles, mental foramen and extraction sockets may be more easily accommodated when a soft liner is used (Travaglini et al. 1960; Gonzalez and Laney 1966; Mack 1989).

(c) Occlusal impact reduction.

For the chronic bruxer where constant grinding, clenching and rubbing of occlusal surfaces of the denture transmit an intermittent shearing stress to the basal seat, a liner may be useful (Laney 1970).

(d) Undercut engagement.

Anatomical undercuts may be utilised thereby eliminating the need for surgery or reduction of the fitting surface of the denture (Mack 1989).

(e) Aid to denture retention.

Utilisation of undercut areas and the frictional characteristic of the liners can aid in retention (Lammie and Storer 1958; Storer 1962; Mack 1989).

(f) Obturators for acquired and congenital defects.

This application tends to be more common in the maxilla where the liner is used to assist correction of soft and hard tissue defects (Lammie and Storer 1958; Travaglini et al. 1960; Storer 1962).

(g) Stabilising registration bases for jaw relation records (Travaglini 1960).

(h) Contraindicated surgery.

Many patients, because of financial and/or general health reasons may not allow surgical correction of soft tissue problems (Travaglini 1960; Gonzalez and Laney 1966; Gonzalez 1977).

(i) Postirradiation.

As a means of prevention of denture irritation, soft liners may be used in patients who have received radiotherapy (Gonzalez and Laney 1966; Laney 1970)

(j) Xerostomia.

In patients with dry mouth from systemic disease or medication, the soft liners help to protect the oral tissues from developing chronic ulcers (Gonzalez 1977).

1.7 Properties required for denture liners

The basic criteria by which liners are judged are their ability to dissipate the forces of mastication and make what was an uncomfortable, potentially destructive denture, comfortable for the patient. Other properties that have been investigated include the following:

(a) Abrasion resistance.

This is the inverse of abrasion loss, which is the volume of a material abraded from a specified test piece when subjected to abrasive wear under specified conditions (Lammie and Storer 1958; Storer 1962). Results of Storer (1962) showed that silicones and acrylics exhibit marked abrasion loss.

(b) Sorptive processes.

In the clinical situation there are two diffusion processes simultaneously taking place. Water or saliva can be absorbed into the liner, and plasticiser or other constituents can be leached out. Application of classical diffusion theories is difficult because most materials do not reach equilibrium states in reasonable periods of time. However this is the best method of describing water absorption behavior (Braden and Wright 1983). It is known that when the amount of plasticiser is more than 15 per cent the uptake of water is small. This appears to be the result of plasticiser filling microvoids which would normally accommodate water (Kalachander and Turner 1989). For silicones, water absorption levels are low and tend to be governed by the amount of inorganic filler. The absorption of matter in acrylic based materials is generally high and controlled by the type of plasticiser used (Wright 1975; Wright 1981).

Absorption of water leads to swelling which may further result in a reduction of bond strength and distortion at the denture base interface (Bates and Smith 1965). In a material containing a high ethanol concentration the diffusion processes result in weight loss, shrinkage and hardening of the material (Braden and Causton 1971). Kazanji (1988) has shown that the fluid

uptake is lower but the weight loss is greater in artificial saliva when compared to water. The increased weight loss is thought to be due to the plasticisers being more soluble in ionic solutions and the lower uptake of fluid is the result of ionic impurities occupying microvoids in the polymer.

(c) Effects on mycotic growth.

Mycotic infection is considered the most important aetiological factor in denture stomatitis (Makila and Hopsu-Havu 1976; Wright 1980; Wright et al. 1985; Burns et al. 1987). The effect of Candida Albicans on the oral mucosa is thought to be mediated by enzymes and endotoxins eliciting a delayed hypersensitivity response (Wright 1980). Makila and Hopsu-Havu (1976) found that in 82 per-cent of his patients there was at least one positive fungal culture. They concluded that the mycotic flora's ability to adhere to the liner made it difficult to keep the material clean. Burns et al.(1987) found that none of the materials they tested had an inhibitory influence on the growth of Candida Albicans. The fungus was found to penetrate the inner portion of all samples. Wright et al. (1985) were able to isolate yeasts from 66 per-cent of the subjects tested. Wright (1980) found that four among seventeen materials tested inhibited the growth of C.Albicans. Three were silicone rubber materials and the fourth a natural rubber compound.

(d) Effect of denture cleansers.

Effective cleaning of soft liners is important not only for cosmetic and social reasons but also to prevent microbial growth. A study by Goll et al. (1983) showed that gross changes occurred when eight different liners

were placed in certain cleansers. Davenport et al. (1986) indicated that the commonly used cleansers did not have an adverse effect on the soft liners, and concluded that a hypochlorite solution is the best alternative in daily maintenance of the liner. Gettleman et al. (1983) investigated modifying existing liners with a metal-hydrogen peroxide complex. He believed that the chemical released over time would have an inhibitory effect on Candida Albicans and Staphylococcus Aureus. Overall, both micro-organisms were affected by the liner.

(e) Adhesion to the denture base.

The successful construction of a denture using two different materials relies in part on a satisfactory bond between the materials. Independent studies by Wright (1982) and Eick et al. (1962) have shown that the strengths of silicone liners and acrylic resin tissue conditioners are generally less than their bonding strengths to poly (methylmethacrylate). Consequently the material tears rather than stripping from the base. Craig and Gibbons (1961) found that the adhesion was not affected by storage in water, and that roughening of the surface of the acrylic base prior to processing liners approximately doubled the adhesion values.

(f) Dimensional stability.

The dimensional stability of liners is dependent on absorption of water and loss of plasticiser. Travaglini (1960) showed that none of the liners he tested were stable. Eick et al.(1962) stated that the amount of material leached out and the amount of water absorbed give an indication of their serviceability in the mouth. Large

weight loss may result in a porous material which would soon become contaminated by oral fluids (Craig and Gibbons 1961). Gonzalez (1977) states in his article that none of the currently used materials exhibit the desired characteristics that would make it a successful permanent liner.

1.8 Rheological properties

Rheological behaviour of liners include two very important phenomena, elasticity or the amount of complete recovery of a material, and viscosity or the amount of flow per unit time. Davenport et al. (1986) consider that liners should return to the original shape as completely as possible after being stressed. Duran et al. (1979) believed that it was desirable for tissue conditioners to adapt to the oral mucosa as it heals and also to absorb stresses during mastication. Soft liners on the other hand were to have limited flow over their life so as to minimise changes in occlusion and also to absorb stresses during function. Harrison (1981) thought that a tissue conditioner should remain soft and exhibit a high elastic recovery. DeMot et al. (1984) think that tissue conditioners should be plastic at first to adapt to the changing mucosa, then after an initial healing period they should be more elastic and act as a cushion. Katakura (1989) believed that the tissue conditioners should be elastic to absorb forces produced during mastication, but also flow according to the recovery of the deformed oral mucosa. Wilson et al. (1969) state that tissue conditioners should possess high elastic recovery with minimal flow properties and at the same time should be

soft. Kawano (1991) believes that the material should be soft, should absorb the forces of mastication and should distribute pressure uniformly on the denture supporting tissues.

At present no international standards exist to guide clinicians in their choice and manufacturers in their reseach and production of denture lining materials (McCarthy 1984; Mack 1989). Likewise no standards exist for the testing procedures. It would seem advisable that a standard specification for liners be developed and it would seem appropriate that two important clinical requirements, flow and elastic recovery should be included in this specification.

1.9 Rheological tests

A distinctive feature of the mechanical behaviour of polymers is the way in which their response to an applied stress depends upon the rate of loading. This dependence upon rate is in marked contrast to the behaviour of elastic solids such as metals and ceramics which, at least at low strains obey Hooke's Law where the strain is proportional to the stress and independent of loading rate. On the other hand the mechanical behaviour of liquids is completely time dependent. It is possible to represent their behaviour at low rates of strain by Newton's Law when the stress is proportional to the strain-rate and independent of the strain. The behaviour of lining materials can be somewhere between that of elastic solids and liquids, a behaviour referred to as viscoelasticity.

The exact nature of the time dependence of the

mechanical properties of a liner depends upon the type of stress or straining cycle employed. For this reason there are several methods for investigating viscoelastic properties.

1.9.1 The creep test.

The creep test as a method of investigation of the viscoelasticity of a material has the advantage of simple instrumentation and is preferred for the long testing time required for those materials having retardation times that extend over a long time scale. It has the disadvantage of insensitivity to the retardation behaviour of the material in the initial short portion of the experimental time scale. A creep test is normally conducted on a specimen having a uniform cross sectional area. A constant load is applied either in tension, compression or shear and the deformation is measured in the direction of load application as a function of time. The deformation detected by such devices as a cathetometer, strain gauge or differential transformer may be measured as a function of time for periods of less than one second to many years (Oglesby 1972). Wilson et al.(1969) and later De Mot et al.(1984) made compression tests (constant stress) on several liners and calculated Young's Moduli. In Wilson's experiment (1969) a constant stress was applied for 1 minute after which time the load was removed and recovery observed. De Mot (1984), using similar apparatus (a balanced beam) observed the length changes of the specimens with a dial gauge during a 10 minute compression. Then the recovery was followed at various times after removing the load. Starke et al.(1972)

simplified this method by recording the original height of the specimen and then applying a load of 200g/cm^2 for 30 seconds, releasing it and measuring the change of height at regular intervals. A further variation of this creep test was developed by Newsome et al.(1988). They compressed the specimen between two glass plates of a parallel-plate plastimeter under a constant stress and then used changes in the diameter of the specimen to calculate the flow of the material. Duran et al.(1979) carried out creep tests which allowed data to be collected for the duration of loading over a range of loads. They derived creep compliance curves from which values of the apparent elastic modulus and viscosity could be obtained. All of these people believed that the properties of softness and elastic recovery should be determined in compression since the principle stresses applied in practice are compressive. McCarthy and Moser (1978a) agreed that compressive load would be the predominant component of any force system acting on the mandibular ridge, but questioned the accuracy of this form of testing. They consider that compression of a lining material does not show the true behaviour of the material as the specimens become distorted on load application. Any increase in load after this deforming point will mean that the force is not acting on the original dimension. They also refer to the frictional end effects whereby the material adheres to the loading plate and/or supporting base. Based on this fact and also work carried out by Rodriguez (1970) who showed that in polymers having strength adequate to allow both tension and compression

tests, elastic moduli were similar, McCarthy and Moser chose tensile testing.

1.9.2 The stress relaxation test.

Stress relaxation tests require slightly more complex instrumentation than creep tests. In addition to requiring a device for detecting deformation, a load measuring device is also required in order to follow the force change with time. A tensile stress relaxation device often consists simply of two clamps between which the specimen is attached. The upper clamp is usually attached to a load detecting cell which is rigidly attached to a frame and the lower clamp can be adjusted up or down in respect of the fixed upper clamp to obtain various deformations in the specimen. Once the lower clamp has been adjusted to obtain the desired deformation in the specimen, the clamp is fixed relative to the frame. The amount of deformation in the specimen can be detected by means of a strain gauge, differential transformer or cathetometer (Oglesby 1972) and is probably the least used of the available testing procedures. Eick et al.(1962) measured the thickness of the specimens before placing them between two glass slabs. Glass slides, which were about 80 per cent of the thickness of the liners were used as dividers to limit the amount of compression, and the whole assembly was clamped. A constant strain of approximately 20 per-cent was thereby created. Murata et al. (1990) using more sophisticated means applied a constant strain of 10 per-cent over a 30 minute period and charted the response.

1.9.3 The dynamic test.

This measures the response of a material to sinusoidal or other cyclic stresses. Braden and Clark (1972) emphasized the misleading results that may be caused by applying the same stress to all specimens. They believed that the constant stress test used by Wilson et al. (1969) subjected the softest materials to greater energy input, and therefore resulted in these materials showing the poorest recovery. This test also tends to exaggerate the stress effect on those materials without chemical cross-linking, eg Visco-gel, because the creep test of 1 minute can be regarded as a one minute stress pulse. This pulse in turn is made up of a train of sinusoidal stress oscillations and hence is related to dynamic measurements. The problem encountered is that the frequencies of these oscillations may well be different from clinically encountered frequencies, and therefore do not allow long-term relaxation effects to operate. The material therefore is not permitted to behave in an expected clinical way. They believed that it was important that viscoelastic properties be measured at rates of deformation appropriate to those experienced clinically (dynamic testing). In practice, the lining materials are subject to cyclic forces such as mastication. Hence, it seemed appropriate to study the response of soft lining materials in this way. They used a torsional pendulum apparatus which applied a torsional stress resulting in simple shear deformation. Although elastomeric materials exhibit non-linear behaviour in tension (Duran et al. 1979), they are usually linear in shear up to high strains. In another study Braden (1970b) showed that for softer materials such

as Visco-gel, if the mature gel is compressed by a constant stress or strain, there will be very little elastic recovery when the load is removed. However if a rapid or cyclic deformation is applied the recovery is more complete. This method of testing was also used by Wright (1981) and Tulachka and Moser (1989).

1.10 Dimensions of Test Samples

In order to estimate the average tissue contact area of a complete mandibular denture, McCarthy and Moser (1978b) selected an average size edentulous cast onto which he adapted self-curing acrylic resin. While the resin was still soft the base was removed and spread out to form a flat plane. Upon curing this flat plane was outlined on graph paper and the area was calculated. The mandibular base was approximately 31 cm^2 in surface area.

Thomas and Mori (1990) in their compression test showed that the surface area of both the loading plate and the specimen was important. This was especially true for the pre-loading phase of the experiment. They found, utilising small cross sectional area samples and a small loading plate that it was impossible to obtain a straight base line. This was due to the specimens deforming under the weight of the assembly before the load was applied. If calculations were to be carried out based on these tracings, any deviation from a straight base line would make the measurement erroneous and misleading.

Numerous studies have utilised specimens with thicknesses around 20 mm (Wilson et al.1966; Braden 1966; Wilson and Tomlin 1969; Starke et al.1972; McCarthy and

Moser 1978; Duran et al.1979; Robinson and McCabe 1982; De Mot et al.1984). These thicker samples are used in an attempt to eliminate specimen distortion during both processing and testing by having an adequate bulk of material. while thicknesses of this order do give a more accurate representation of the mechanical properties of the material, as De Mot (1984) concluded in his experiment, there is a need to test 2 mm thick samples to ascertain the clinical relevance of the results obtained from the 20 mm samples. A report by McCarthy and Moser (1978a) emphasized the importance of the material being at least 2 mm thick so as to ensure accuracy in any tests carried out on lining materials. Ellis et al.(1980) stated that it was important to use samples of about the same thickness as would be applied to a denture. Wright (1976) found a substantial benefit in softness of the bonded soft lining if the thickness is increased from 1 to 2 mm, while a smaller benefit if it is increased to 3 mm and a still smaller benefit if it is increased to 5 mm. Studies such as this have led to recommendations being made for 3 mm thickness specimens for clinical use (Wright 1976; Schmidt and Smith 1983).

1.11. Conditions of testing.

These include specimen age, the load applied, temperature and storage conditions.

McCarthy and Moser (1978b) in a study of tissue conditioners question the methods of compressive loading generally used. They see difficulties in drawing generalised clinical conclusions from studies in which the

specimens were loaded after short ageing times (minutes to a few hours) and the recovery rates recorded over extended periods. They point out that these methods are not considered of major clinical significance because the materials are not utilised in this manner in practice. They see more meaningful data resulting from the loading of longer aged specimens and the recording of the degree of recovery over short time periods. De Mot et al. (1984) and Braden (1966) have both shown that the properties of Visco-gel change markedly in the first hour after processing.

During function the loads are applied over much shorter times than were used in many studies. Duran (1979) took readings at 5, 15, 30, 45, and 60 seconds, and 2, 3, 4, and 5 minutes after load application. DeMot et al.(1984) and Wilson (1978) both used a 10 minute compression time, Newsome et al.(1988) used 60, 120, and 240 seconds, while Robinson and McCabe (1982) took readings every 10 seconds for 1 minute, followed by a reading at 5 minutes, then every 10 minutes for 1 hour. None of these tests examined the recovery of the specimens after removal of the load. Thomas and Mori took readings up to 8 weeks (personal communication).

The forces developed within the oral cavity are numerous in character and varied in magnitude and those acting on the mandibular ridge may be intermittent. This can occur during mastication and swallowing. Biting forces are transmitted through the bolus to the opposing teeth whether the teeth make contact or not. These forces are essentially vertical, are of short duration and are

restricted to short periods of time. They have reported values of 10.6 - 22.0 Newtons (De Boever et al.1978) and 17.6 - 44.7 N (Bearn 1972). The tooth contacts developed during swallowing are usually of longer duration than those during mastication (Glickman 1969) but tend to occur more frequently at about 600 times a day (Lear 1964). The forces developed range from 9 - 80 kg/mm^2 for a lower denture (Ohashi et al.1966) and are essentially vertical in direction.

Constant forces are also acting on denture liners. The weight of the denture is usually only very small in size, but over the course of a day may be of consequence. Forces deriving from the oral musculature are predominantly horizontal and are determined by the balance between the various muscle groups' action and magnitude of contraction (Brill et al.1965). The forces due to tooth holding, clenching or bruxing habits are not only large, but also of long duration, as the dentures are held together under constant pressure (Ortman 1966). Whinery (1975) believes that every patient with extreme mandibular atrophy has had a tooth-holding or clenching habit.

As can be seen from the aforementioned, the designing of a single experiment which reproduces all of these conditions, let alone the numerous other vectorial permutations of the forces would be virtually impossible (McCarthy and Moser 1978a). In an attempt to simulate the clinical situation, Newsome et al.(1988) applied two different loads to each specimen. The first was referred to as the "minor load". It was 100 ± 1 g and attempted to reproduce the clinical load exerted when the denture was

seated initially and the patient comes into light contact. The second load was the "major load". This was 1000 g and represented the load exerted when the teeth are brought more firmly into contact. Duran et al.(1979) applied a creep testing procedure in an attempt to address the problem of varying forces. He stated that a creep test allows data to be collected for the duration of loading and over a range of loads. Since this form of testing reproduced constant loads, Duran devised a separate dynamic testing method to study the cyclic behaviour of the specimens. Other studies looked at either the specimen's behaviour under constant load or under dynamic load, but not both.

In use, soft liners are constantly bathed in saliva and when out of the mouth they are usually immersed in either solutions of denture cleansers or water for storage. Braden (1983) tested and stored specimens of liners in water because liner properties have been observed to change when stored in water (Eick et al.1962; Wilson and Tomlin 1969). Ideally it would be more pertinent to carry out the study in artificial saliva. A study by Kazanji (1988) found that the percentage solubility of all the specimens he tested were significantly higher in artificial saliva than in water (probably a result of plasticisers being more soluble in ionic solutions than in water). Conversely, the percentage absorption of artificial saliva was significantly lower than that of water. These findings were confirmed by Ellis (1979). He showed that for ethanol-containing materials, while the initial desorption of ethanol was similar for the two solutions, the variations in weight for the rest

of the study was significantly different. In fact, he concluded that sorption studies in pure water were inadequate when assessing the clinical importance of water sorption by liners.

Wilson et al.(1969) stressed the importance of carrying out tests at mouth temperature but gave no reasons why. McCarthy and Moser (1978) saw the temperature difference of 16^0 C between mouth and ambient conditions as having only slight effect on the properties of the materials and therefore chose ambient temperature to test in. Braden (1964) however, found that the diffusion coefficient of polymers is affected by temperature variations and concluded that testing should be carried out at 37^0C.

1.12 Aims of this study

Denture liners represent a class of materials in which great variability exists in both terminology, reported properties and applications (Sections 1.4, 1.5, 1.6, 1.7). This has arisen because rheologically speaking they are an extremely heterogeneous group of materials with behaviour varying from predominantly elastic to predominantly viscous. Also, no guidelines for manufacturers or clinicians have been set by either standards committees (Section 1-7) or clinical studies and reference is made to either resilient liners or soft liners (Section 1.4). The purpose of this study is to clarify the confusion in terminology by developing a new rheological testing method for denture liners. Once the procedure is perfected it should be possible to show that liners do indeed represent

a wide spectrum of behaviours.

It was also hoped to show the changes in the lining materials over various time periods. Previous studies have generally examined the rheological properties after very short ageing times, (Section 1.10) where in reality these materials may be called upon to function for extended periods, and it is important to know whether the properties change. If any obvious trends could be shown then it may be possible to group the liners on a time-in-use basis (Section 1.4).

In this study only Molloplast B and Visco-gel will be examined as they are recognised by most clinicians as two of the most commonly used denture lining materials and pilot studies showed them to represent totally different rheological classes.

Chapter 2

MATERIALS AND METHODS

2.1 Apparatus

The response of denture lining materials to cyclic loading conditions is important in order to understand in vivo performance of these materials. Based on initial work by Thomas and Mori (1990) a dynamic compressive creep test was developed in an attempt to overcome the problems with previous testing procedures (Section 1.5).

The apparatus consisted of a linear variable differential transducer (LVDT)[1] supported by a brass casing and mounted on a jig assembly (Figure 1). At the lower end of the LVDT was attached a circular brass foot (10 cm^2) which applied the compressive force to the specimens. At the upper end of the LVDT was a slip joint arrangement whereby the upper end slid outside a loading table. The loading table was connected to an air pressure regulator to which was attached a supporting fork which in turn raised or lowered the table. A rod extending from the loading table slid within the LVDT assembly until a silicone washer on the rod engaged the superior end of the LVDT assembly.

This arrangement of the apparatus caused several initial problems. Firstly, because it is a slip joint, a smooth movement between the two arms is essential. After repeated use of the apparatus some friction developed between the two surfaces and in order to remedy this problem it was important to lubricate the joint with a

[1] 050HR, Schaevitz Engineering, Pennsauken, NJ, USA.

silicone spray. It was equally important not to overuse the spray, as excess might have run down the transducer arm. Secondly, the stabilising arm that controls the load must not be allowed to rotate and interfere with movement. A circular design for the arm was therefore used as it allowed both easier visualisation of the centring of the arm and fixation by two screws to stop rotation.

A weight was placed on the table and released instantaneously by means of a toggle switch. This switch was situated between a source of compressed air and the regulator. By closing off the air path the load was applied, and then by allowing air flow the load was lifted. This arrangement was a big improvement on the manual lowering and raising used by Thomas and Mori (1990). The only problem encountered with this system was that of deciding how much pressure was needed to raise and lower the load instantaneously. The regulator used had no gauge, and eventually the successful pressure was obtained by trial and error.

Specimens were placed on a glass slab which was housed within a water bath. The water bath consisted of Perspex walls and floor with a brass tube entering one side, running around the perimeter of the bath and exiting on the same side. Water (37±0.5^{0}C) was pumped through this tubing by means of a temperature controller[2] . The bath was filled with water to a level just below the top of the specimen being tested and the temperature monitored by means of a thermocouple (Type K) connected to a chart recorder[3] (complete apparatus shown in Figure 2).

[2] Thermo Circulator, Churchill Instrument, Perivale, England.
[3] LR 4210, Yokogawa Electric Corp, Tokyo, Japan.

The movement of the LVDT core was recorded at a chart speed of 60 mm/min. The recorder was calibrated by using one major vertical square to equal 100 um which translated into a total vertical spread of 1 mm.

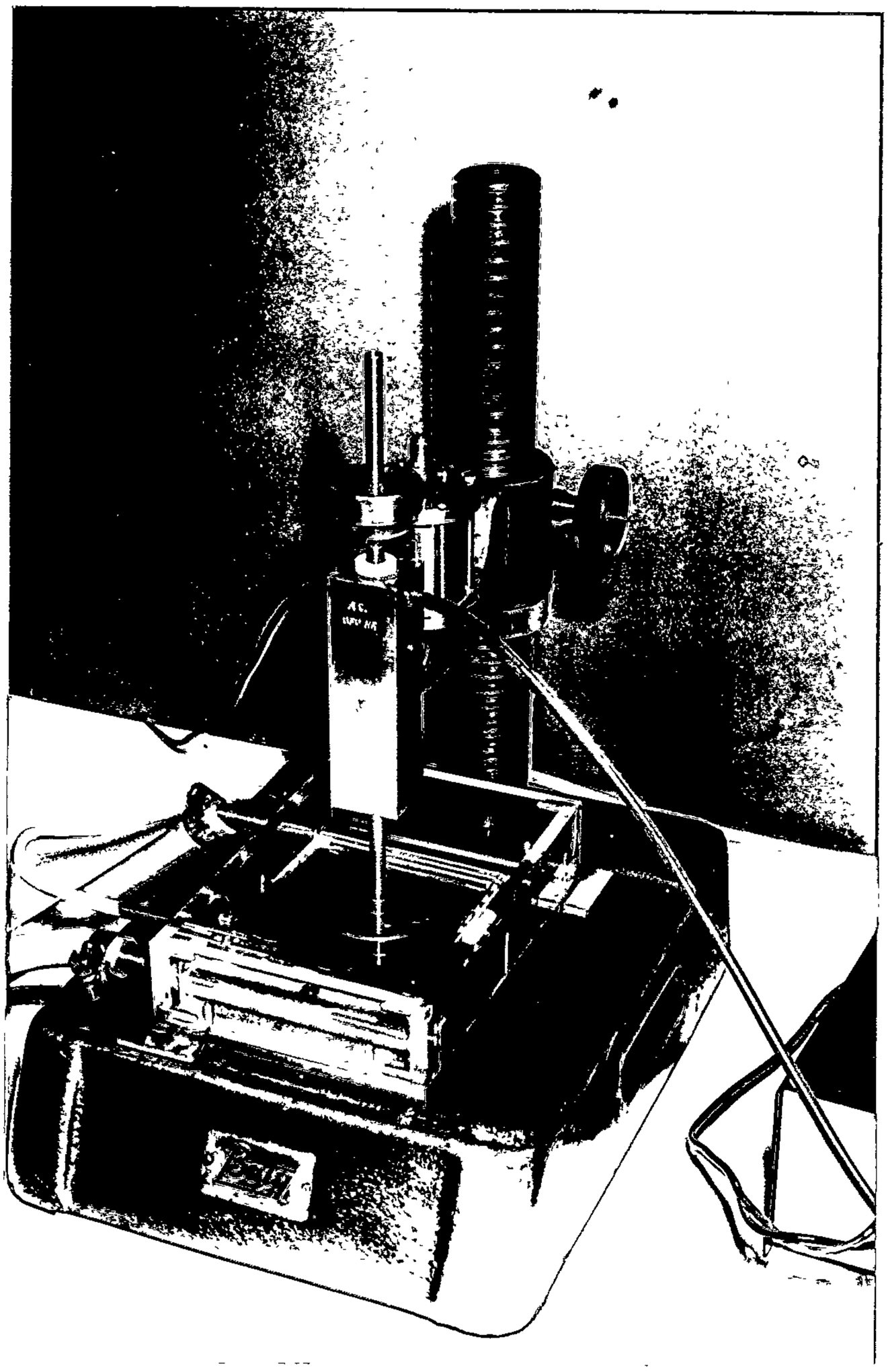

FIGURE 1: THE LOADING APPARATUS

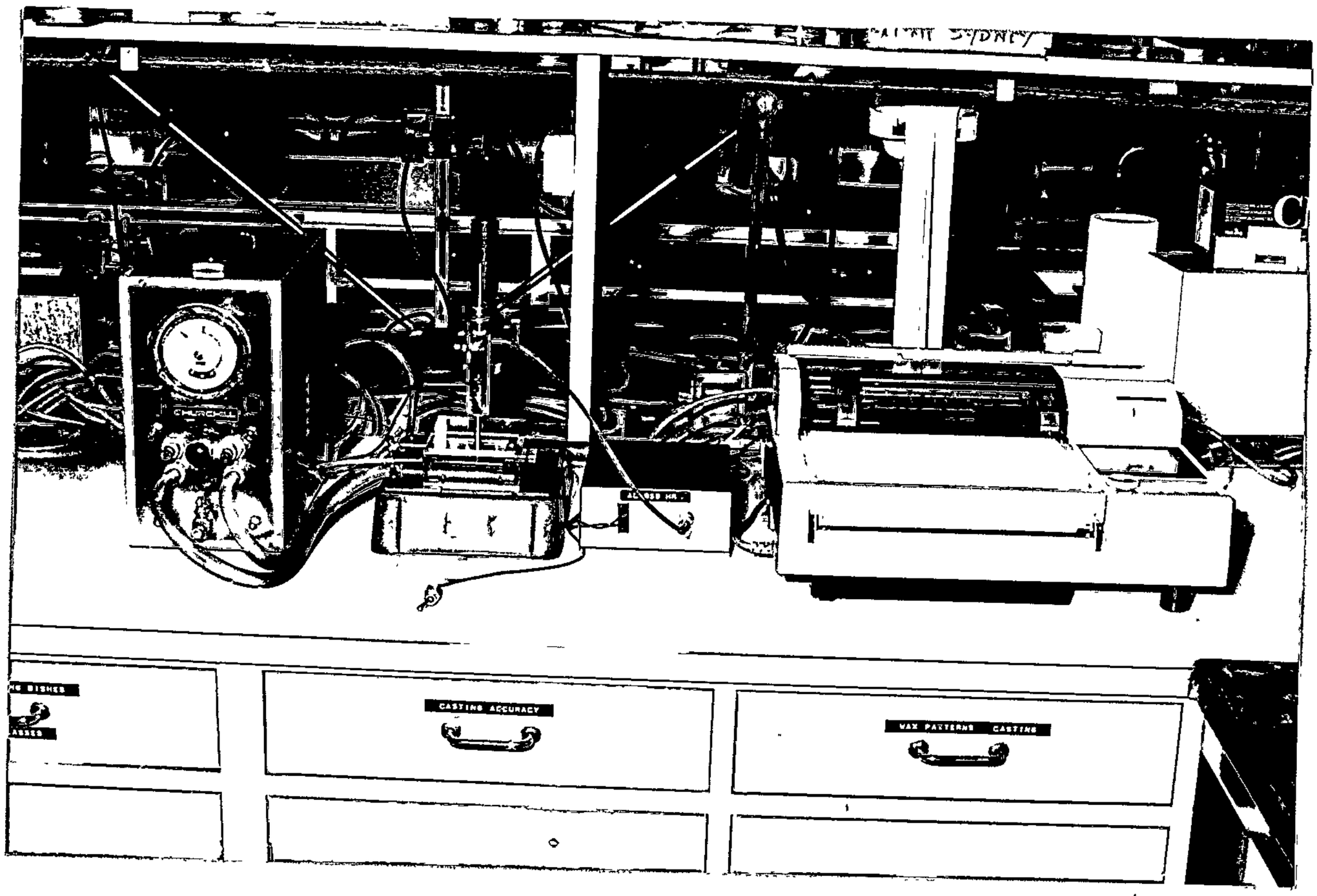

FIGURE 2: THE ENTIRE TESTING ASSEMBLY

It is important to check that the recording paper used is set for metric measurements in both the horizontal and vertical axes as some American companies use a mixture of both imperial and metric measurements. It is also important that the arm to which the transducer is attached is made of a non-magnetised metal. Otherwise the metal is able to set up its own magnetic field which in turn can result in aberrent readings. Also the transducer's position needs to be set to coincide with the most predictable, reproducible part of the graph, ie away from its extremities.

2.2 Preparation of specimens.

Following on from the work of Thomas and Mori (1990) the loading assembly was made as light as possible (38 g) to reduce deformation of the specimen before the test. Pilot tests on Visco-gel specimens having a cross-sectional area of 10 cm^2 showed that the resulting stress provided negligible deformation. As previously described the area of the loading plate was slightly larger than 10 cm^2 in order to cover the entire surface of the specimen.

Initially specimens having thicknesses of 1, 3, 6, and 9 mm were prepared. Tests on the 1 mm samples supported McCarthy and Moser's (1978a) view that such thin specimens are difficult to prepare and to test. The difficulties in preparation became apparent on removal from the mould as the samples either distorted or tore due to inadequate thickness.

The 3, 6 and 9 mm samples gave very similar tracings when loaded and unloaded, a fact supported by Wright (1976). Because of this result and also the fact that a 3 mm liner thickness is generally recommended by clinicians (Section 1.10) this thickness was finally selected for the present study.

Brass cylinders machined to the desired cross-sectional area of 10 cm^2 were used for the preparation of test specimens (Figure 3). The cylinders accommodated a Teflon base which formed the bottom surface of the specimens and allowed them to be extruded once set. The height of the specimen was set by means of gauge blocks (3 mm in height). Two of these were diametrically placed opposite each other between the foot of the Teflon base

and the lower edge of the cylinder. Once the specimen had aged for a period the gauge blocks were removed and the Teflon base forced upwards so that the lower edge of the tube and the Teflon bung were in close contact. This in turn caused specimens to be extruded from the upper end of the tube.

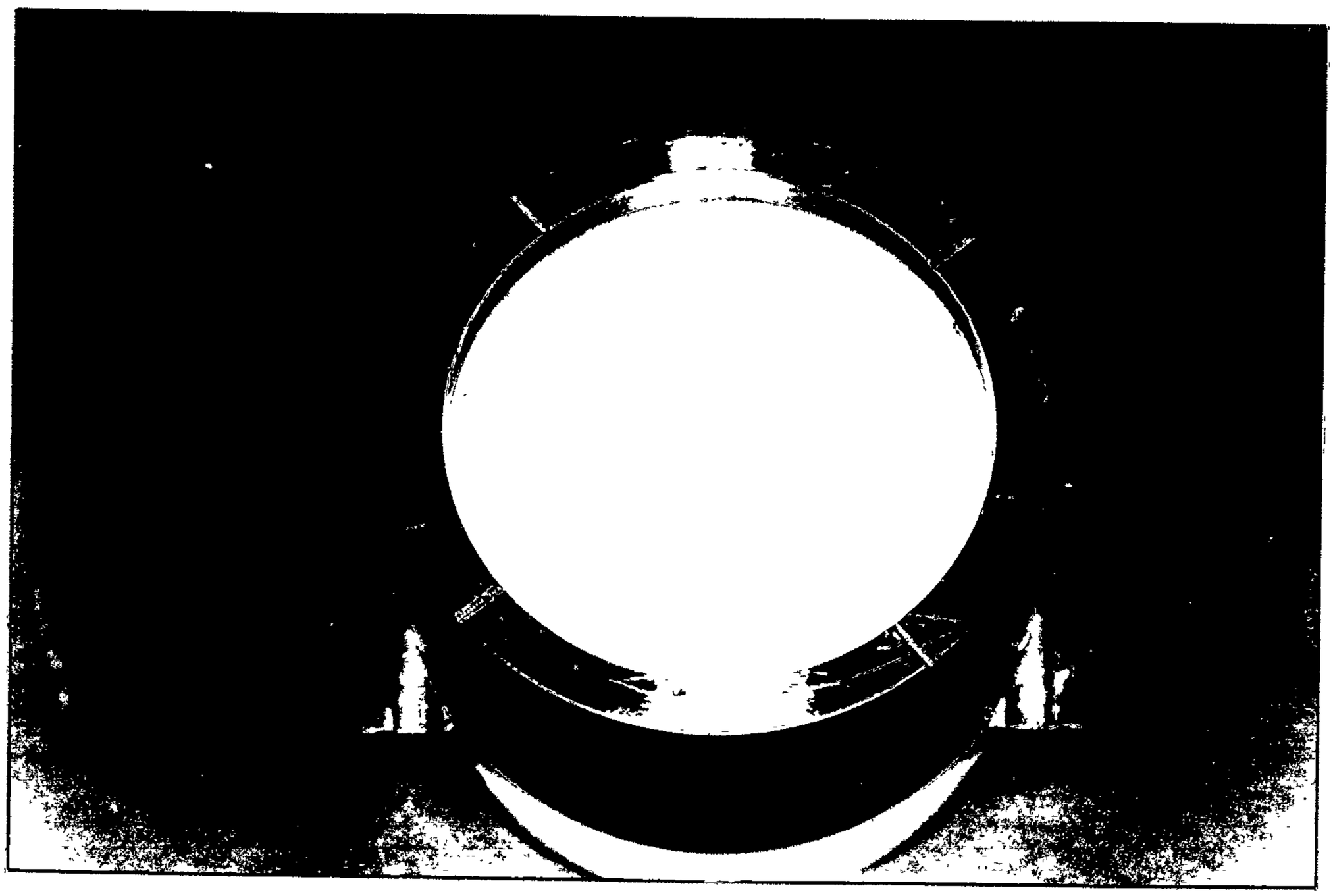

FIGURE 3: SPECIMEN PREPARATION MOULDS

Visco-gel[4] was supplied as a powder and liquid. For each sample 3 g powder was mixed into 3.25 g of liquid by spatulating for 30 sec. The mix was transferred to the mould and filled until a slight excess was apparent, being careful to minimise air entrapment. A lubricated glass cover was placed over the top of the mould and pressed down in order to establish correct specimen height. In

[4] Batch No. JD 136, JE 56.

pilot runs a problem existed with the specimen sticking to the glass, but on spraying the glass with silicone the problem was rectified. Two minutes after the initiation of mix the specimen contained in the mould was placed in an incubator controlled at 37+0.1^{0}C for 1 hour. The specimen was then removed from the incubator and the glass cover was carefully lifted from the top of the mould. As soon as the specimen was extruded from the mould and any flash trimmed with a scalpel, it was weighed using a chemical balance[5] , and then transferred to a device (section 3.3) for the measurement of thickness.

Molloplast-B[6] specimens were prepared according to the manufacturers instructions. For this silicone discs of light body Reprosil[7] (LD Caulk, Dentsply, Milford, Delaware) were first made in the moulds and invested in plaster. Once the plaster had set the flasks were separated and the discs carefully removed, Molloplast-B packed in the cavity and heat cured at 100^{0}C for 60 minutes. Once curing was complete the specimens were removed and the flash trimmed using a scalpel. This was followed by the measurements of mass and thickness.

Prior to each testing specimens were weighed and the thickness measured in the same way as the initial measurements. Excess water was removed by shaking each specimen 6 times.

2.3 Measurement of specimen thickness

For the measurement of the thickness of Visco-gel and

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[5] AE 163, Mettler Instrument Co, Greifensee, Switzerland.

[6] Batch No. 900634

[7] Batch No. 042590

Molloplast B specimens a device similar to the cyclic loading apparatus was developed. It consisted of a LVDT onto which was attached an extension arm which terminated in a flat aluminium foot (cross-sectional area of 15 cm^2). The specimens were placed beneath the foot and displacement was registered as a voltage which was converted to a millimetre reading.

Calibration of the apparatus was carried out using gauge blocks in 0.5 mm increments from 1 mm up to 6 mm. For each increment the voltage output from the LVDT was recorded to develop a conversion equation. The weight of the extension arm and foot produced a strain in the Visco-gel samples, although this (2.0g/cm^2) was much lighter than that used in the cyclic test. The readings were taken after 1 min of the assembly being in place.

2.4 Testing.

The specimens were tested at 1 hour, then after 24 hours and daily up to 1 week, and weekly up to 6 weeks.

The cyclic loading/unloading continued for 1 minute and the recovery time was arbitrarily set for 30 seconds or until flat line recovery was attained. During the 1 min loading/unloading cycle there were 15 loadings and 15 unloadings alternating at 2 second intervals, timed with a stop-watch.

Three separate loads, 100, 200 and 400 g were applied by adding masses to the 38 g loading arm to make up these values. Since the specimens were of 10 cm^2 area, the stresses developed were 10, 20, and 40 g/cm^2. The three masses were chosen to show whether any linearity exists

between the load applied, the deformation and the recovery. For each material six specimens were prepared for each testing load. Five of these were test specimens and one was a control. All graphs and tables presented are means of the five specimens.

Chapter 3

Results

3.1 Thickness measurement

Table 1 (Appendix p80) and Figure 4 show thicknesses of the Visco-gel (hereafter VG) specimens measured over 6 weeks. Thickness values at 1 hour before the first loading were more varied than the 1 day readings. The loaded samples kept relatively stable dimensions following loading. Since there was only one control specimen for each load, the average of the three control specimens is also shown in Table 1 and Figure 4. The unloaded controls remained thicker than the test samples and showed considerable variation.

Thicknesses of the Molloplast B (hereafter MB) specimens measured over 6 weeks are shown in Table 2 (Appendices p80) and Figure 5. Thickness values at 1 hour were more varied than the 1 day readings. Both control and test specimens remained relatively stable over the 6 week period.

3.2 Mass measurement

Mass changes of the VG specimens measured for the 6 weeks are shown in Table 3 (Appendices p81) and Figure 6. The 100 g specimens were much lighter than either the 200 or 400 g specimens, reflecting the fact that these were the first specimens made and consequently displayed initial difficulties in eliminating some of the porosity in specimen preparation. The differences were maintained throughout the course of the study. Little change occurred

in both test and control specimens.

The MB specimens also showed only minor variation over the study period (Table 4 and Figure 7).

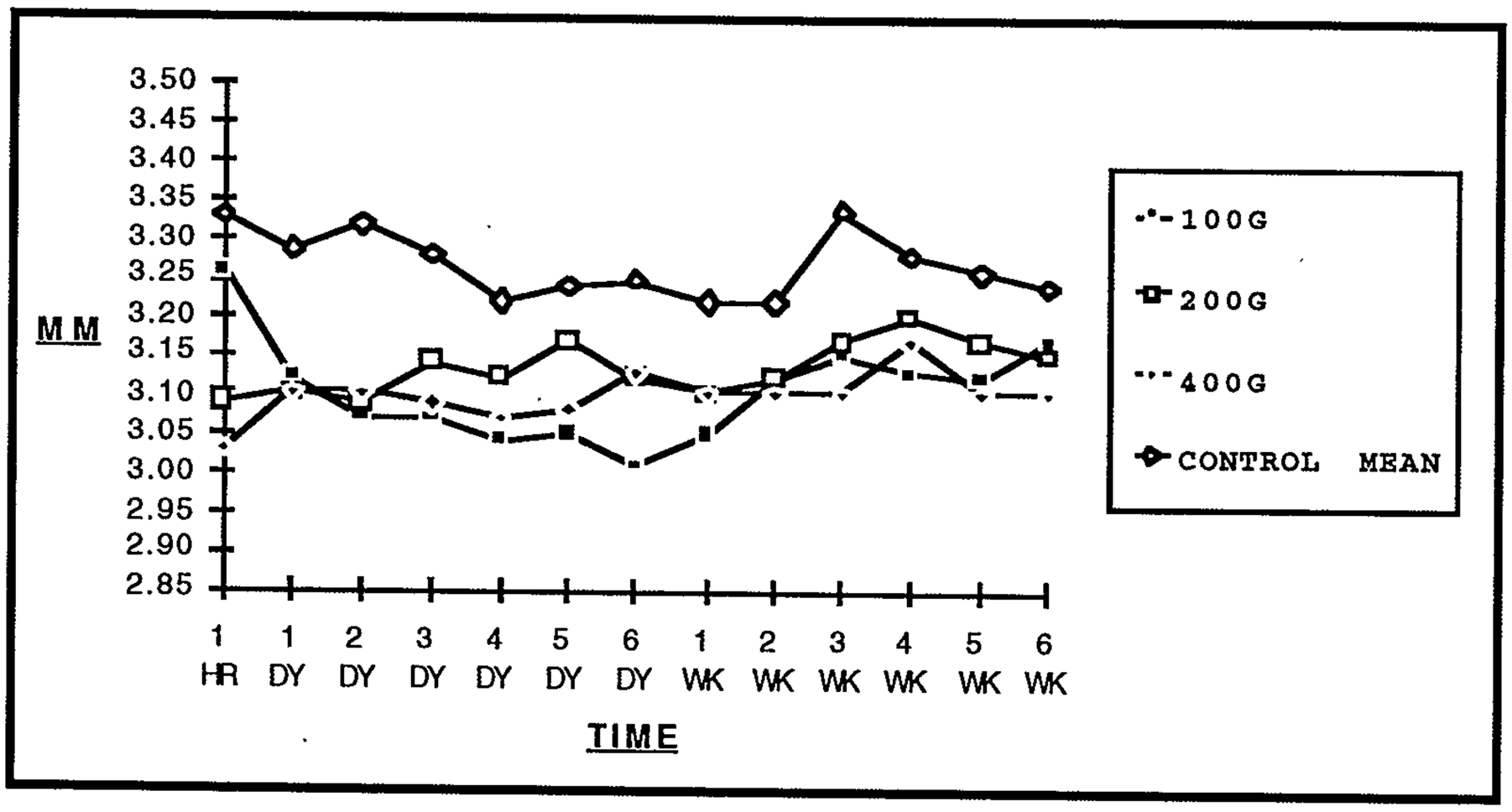

FIGURE 4:VISCO-GEL THICKNESS CHANGES

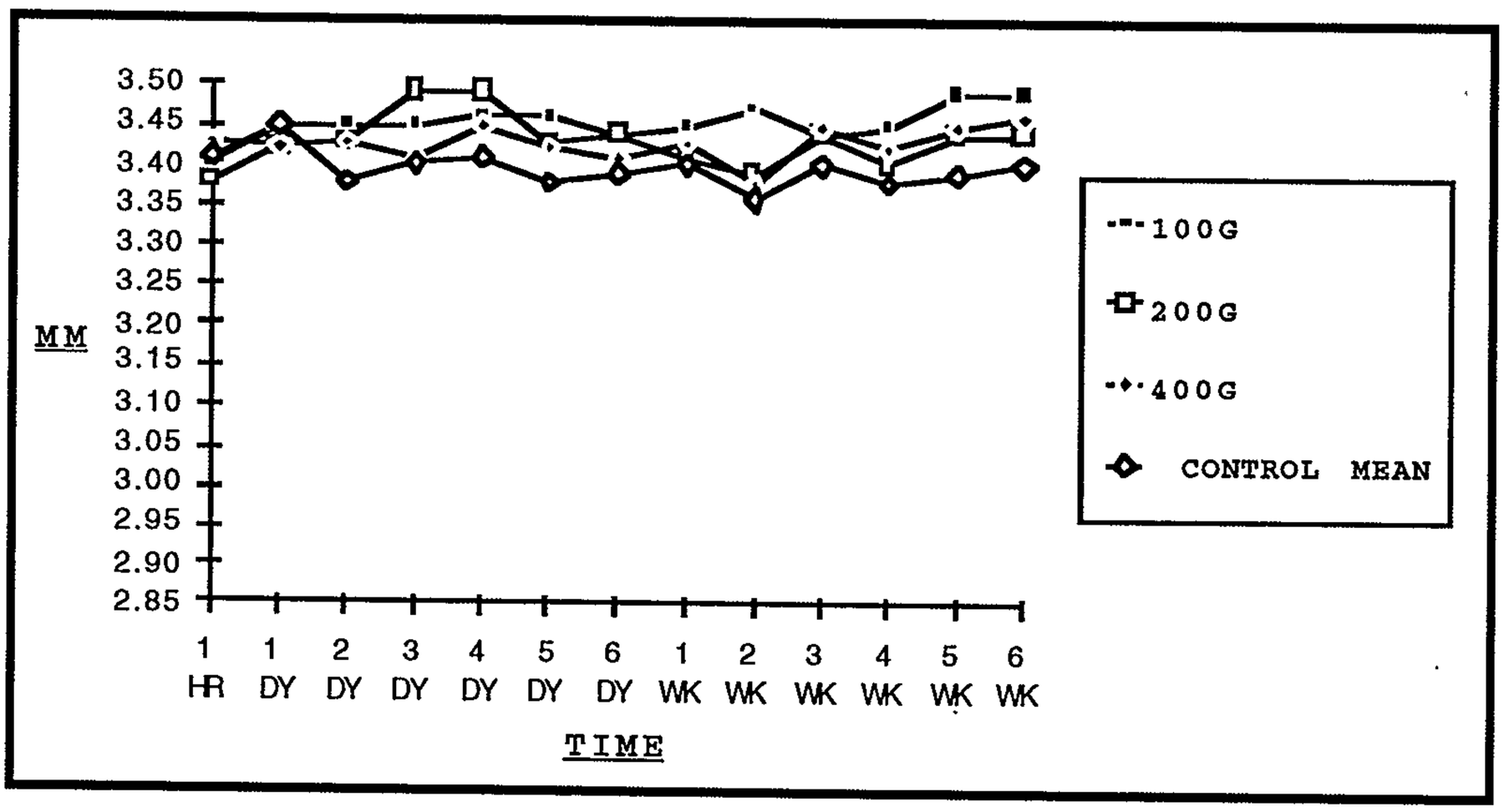

FIGURE 5:MOLLOPLAST B THICKNESS CHANGES

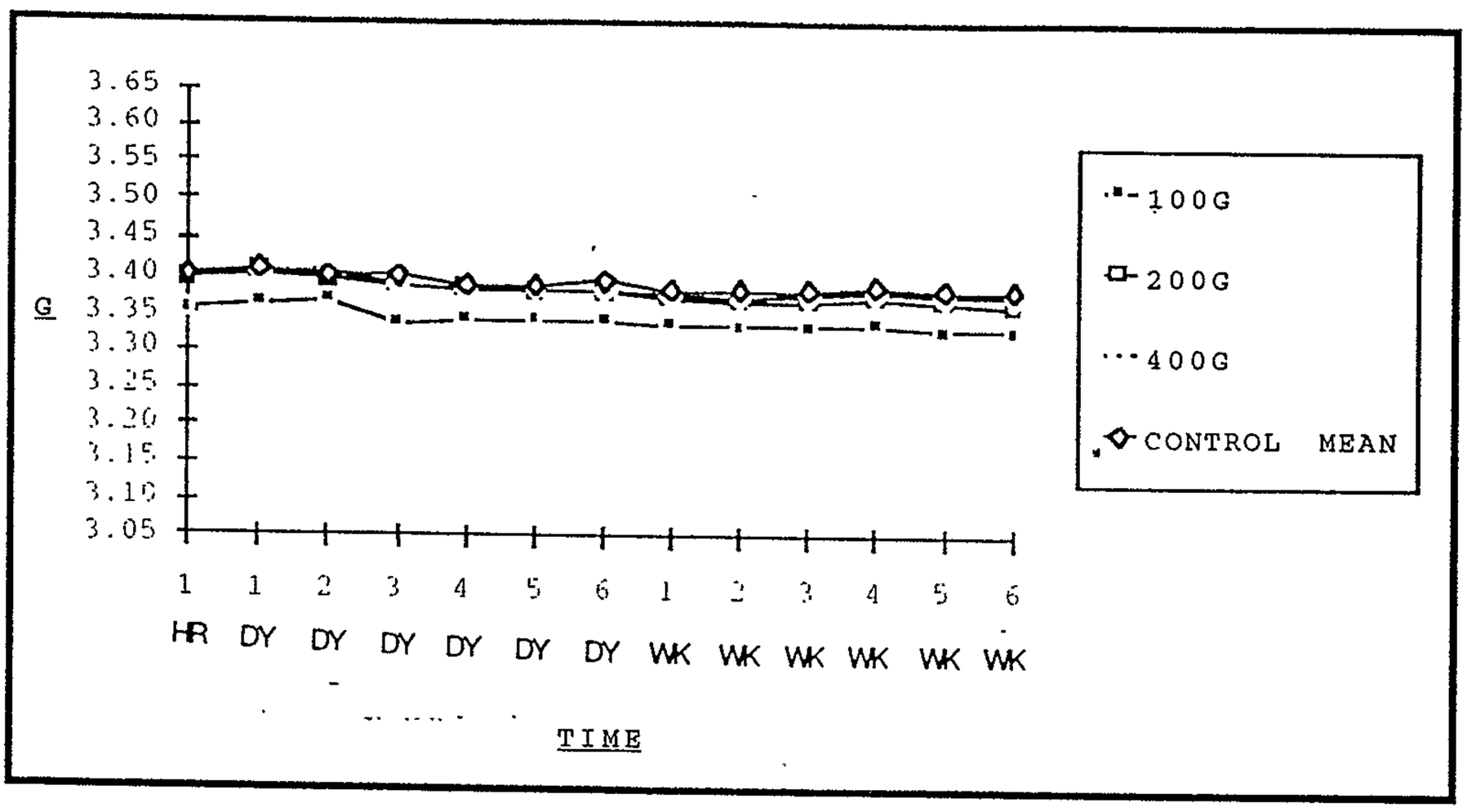

FIGURE 6:VISCO-GEL MASS CHANGES

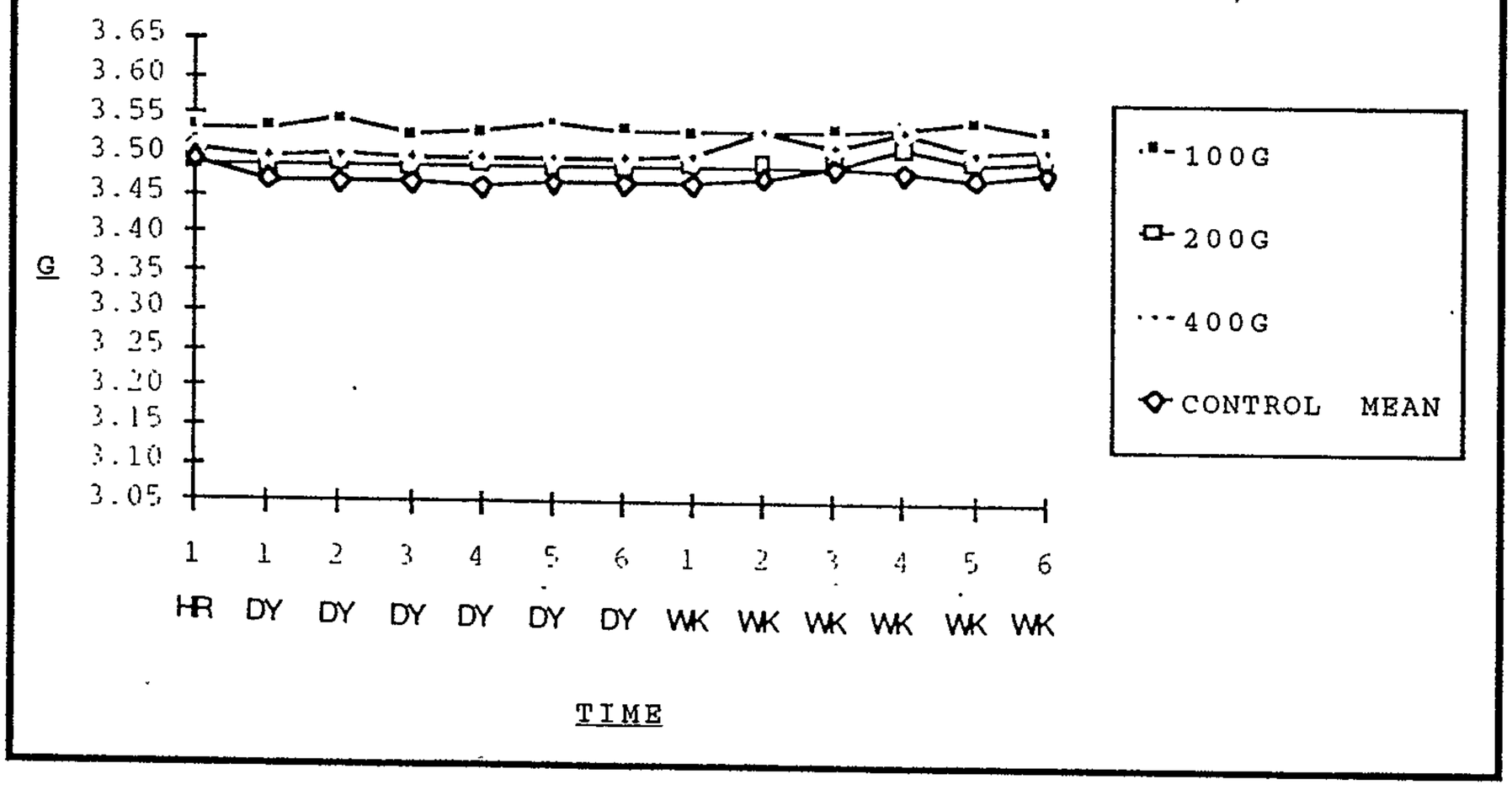

FIGURE 7:MOLLOPLAST B MASS CHANGES

3.3 Cyclic creep test

3.3.1 Visco-gel

Figure 8 shows a representative curve obtained from the cyclic creep test of VG. The initial load (38 g) distributed over the cross-sectional area of the specimen (10 cm^2) generally gave a steady base line from the start of the recording A_0, up to the point A_1 where the cyclic loading was commenced.

On removal of the specimens from the storage containers, stresses were inadvertantly introduced. On standing in the containers, some of the specimens underwent a phenomenon referred to in other studies as slump. In other words the specimen distorted under its own weight. Since the bottoms of the containers were not perfectly flat, these specimens adapted to the contour of the surface, thereby causing some distortion.

These stresses were occasionally shown by a bend in the initial flat line preloading trace (A_0 to A_1). If the specimens were distorted in any way, this straight line section of A_0 to A_1 would demonstrate deviation because the weight of the assembly would only be resting on one or two points on the specimen, not the whole surface. This in turn would make the determination of rheological indices more difficult because of the lack of consistency in the initial reference position.

Compression of the specimen during the first two seconds is shown by the line A_1 to B_1, at which time the load was released. A_2 is both the recovery of the specimen two seconds from this release of the load and also when the second loading was applied. A_{15} to B_{14} is the last

loading (A_{16} to B_{15} is not used for this measurement because it was difficult to discriminate between immediate elastic response and delayed response for this section of the trace). A_{16} is the final response of the specimen for a duration of one minute from the last loading. A straight line response was recorded during this final period.

From these points, three responses were calculated:

(1) Initial elastic response - $E_1 = B_1 - A_2$.

(2) Final elastic response - $E_2 = B_{14} - A_{15}$.

(3) Plastic deformation - $P = A_{16} - A_1$.

The raw data E_1, E_2 and P are expressed as a percentage of the thickness of the pre-testing specimen in Table 5.

From the elastic response (E_1 or E_2), elastic recovery was further calculated as a percentage of the displacement. That is: Initial elastic recovery - $R_1 = (B_1 - A_2)/(B_1 - A_1) \times 100$. Final elastic recovery - $R_2 = (B_{14} - A_{15})/(B_{14} - A_1) \times 100$.

Table 5 summarises the percentage recoveries thus calculated.

In the test of VG specimens the 100g load appeared to be too light for the loading apparatus developed. This resulted in the assembly moving up too quickly on release of the load, allowing a film of water to infiltrate between either the bottom of the loading plate and the top of the specimen and/or the bottom of the specimen and the glass slab. On the other hand the 400g load often made the specimen adhere to the glass slab. As a result the specimen was not allowed to recover.

3.3.2 Molloplast B

Figure 9 shows a representative curve obtained from

the cyclic creep test of MB. A_0, A_1, B_1, A_2, B_{14}, A_{15}, A_{16} represent the same points as in the VG results. The initial and final elastic responses (E_1 and E_2) were almost equal for nearly all specimens tested. Therefore, E instead of E_1 and E_2 was calculated from $E_1 = B_1 - A_2$. Permanent deformation (P) used the same points and elastic recovery (R) was calculated as shown in Table 6.

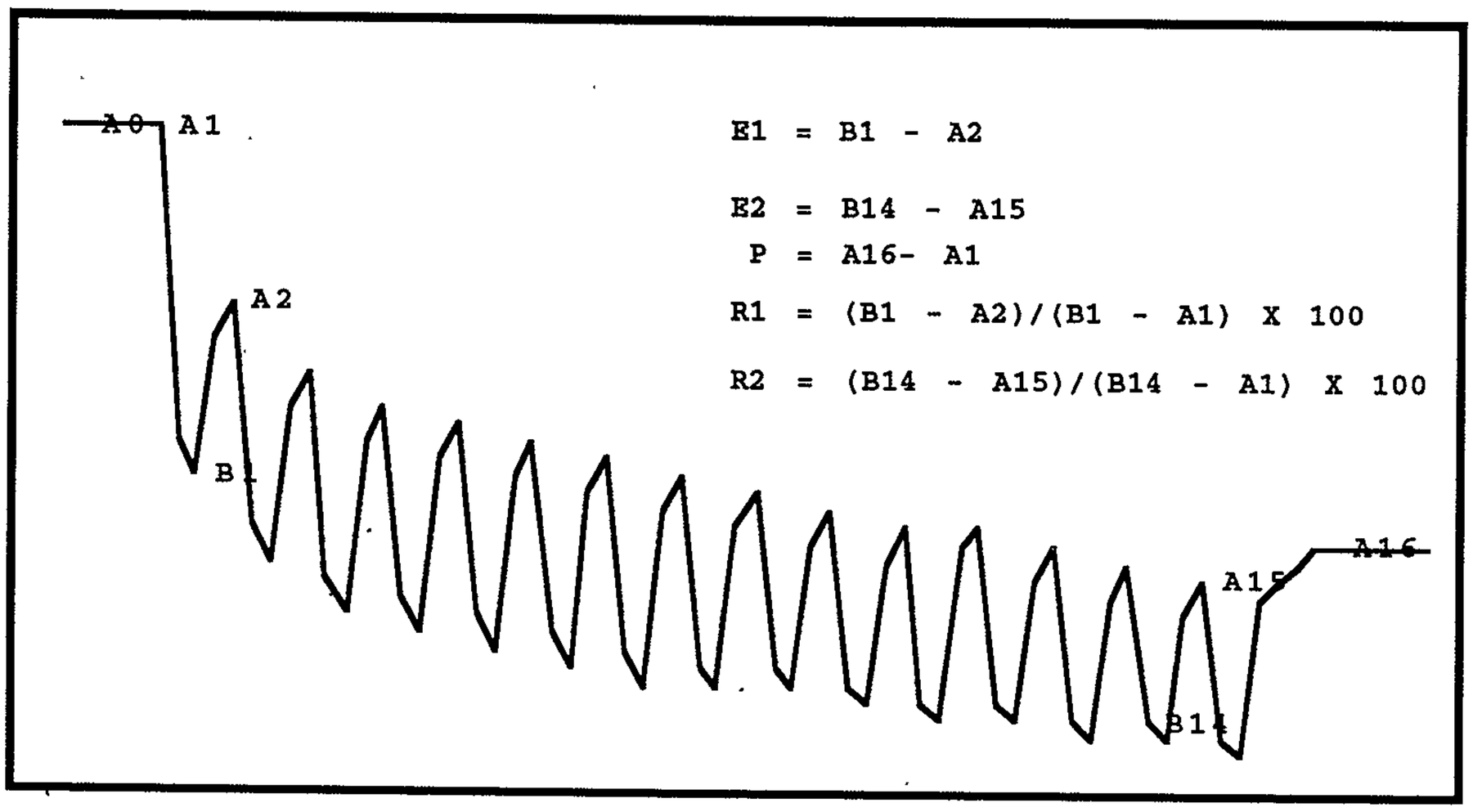

FIGURE 8:VISCO-GEL REPRESENTATIVE TRACE

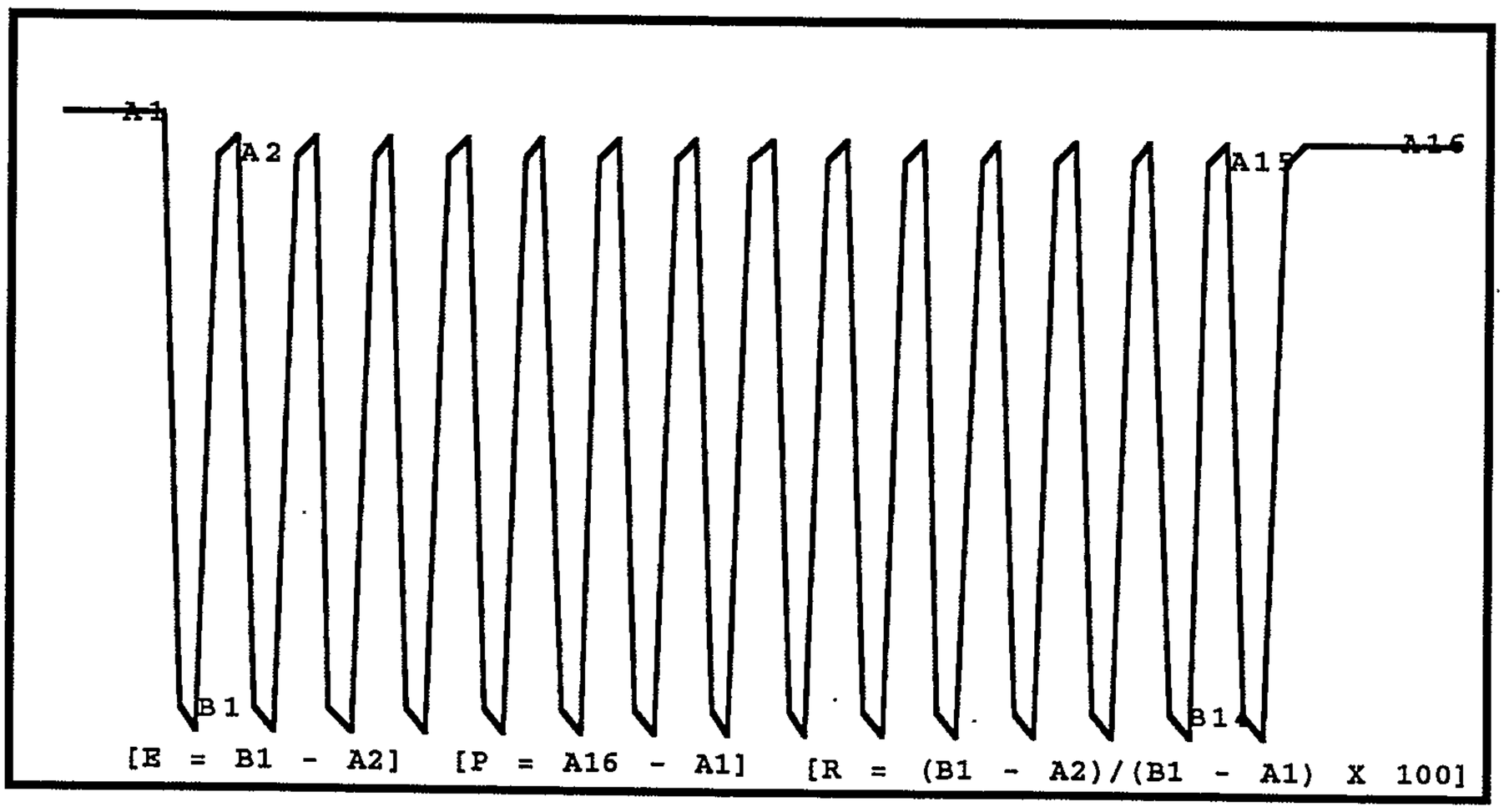

FIGURE 9:MOLLOPLAST B REPRESENTATIVE TRACE

In the test of MB specimens, the loading arm was occasionally displaced back past the pre-loading reference line (A_0 - A_1) on removal of the load. For the lighter loads, 100 g especially the response was affected by a film of water between either the specimen and the loading arm and/or the specimen and the glass slab. The lighter loads were also affected by the air pressure movement of the assembly. Since fine adjustment of the air pressure was not possible for the variation in loads, it was probably too great for the 100 g load and the loading arm was not always solely moved by the recovery of the specimen but was occasionally assisted by the air pressure. At times this problem was compounded by lack of free movement between the transducer and the loading arm. All of these problems tended to occur after the final loading cycle.

3.3.3 Rheological responses

Considering all of the difficulties in both the 100 and 400g VG and MB specimens, the results from the 200 g loading were finally chosen and shown graphically, in Figures 10 (E_1, E_2 and E), 11 (P) and 12 (R, R_1, R_2). Actual tracing for a VG specimen is shown in Figure 13 and Molloplast B in Figure 14.

A trend of decreasing elasticity over time was noted for both E_1 and E_2, although t-tests for E_1 at 1 hour against 1 day, and 1 hour against 6 weeks showed no significant difference between the means at a probability level of 0.05. The larger elastic response (E) of MB specimens resulted in greater variations in their means over the six week period. T-test comparisons show a

significant difference between the means of 1 hour and 1 day, and 1 hour and 6 weeks at a probability level of 0.05.

The plastic deformation (P) for both VG and MB remained quite constant over the six week study. Figure 11 shows that the permanent deformations of MB (less than 2 per-cent of the original thickness of the specimen) are much lower than those of VG (about 5 percent of the original thickness of the specimen) throughout the six week period.

Throughout the study the recovery of VG at the end of the cyclic loading (R_2) was significantly smaller than the initial recovery (R_1). The inherent differences between the two materials are also evident in Figure 12; MB consistently recovered about 90 percent of the deformation loading, while the rates of VG were between 40 to 50 percent at the first loading and 10 to 20 percent at the final loading. These percentages remained constant throughout the duration of the study.

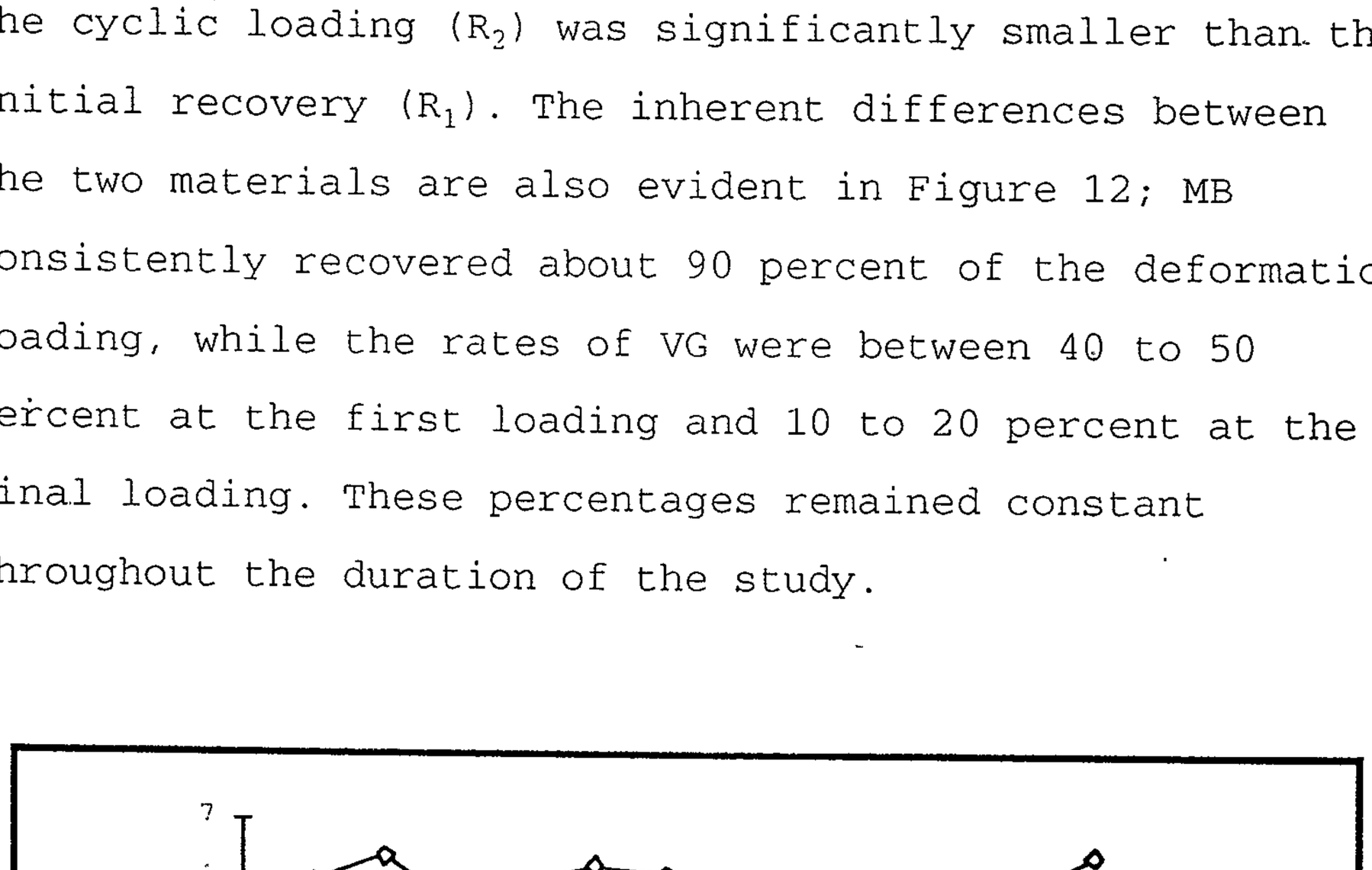

FIGURE 10:ELASTIC RESPONSE FOR 200G LOADING

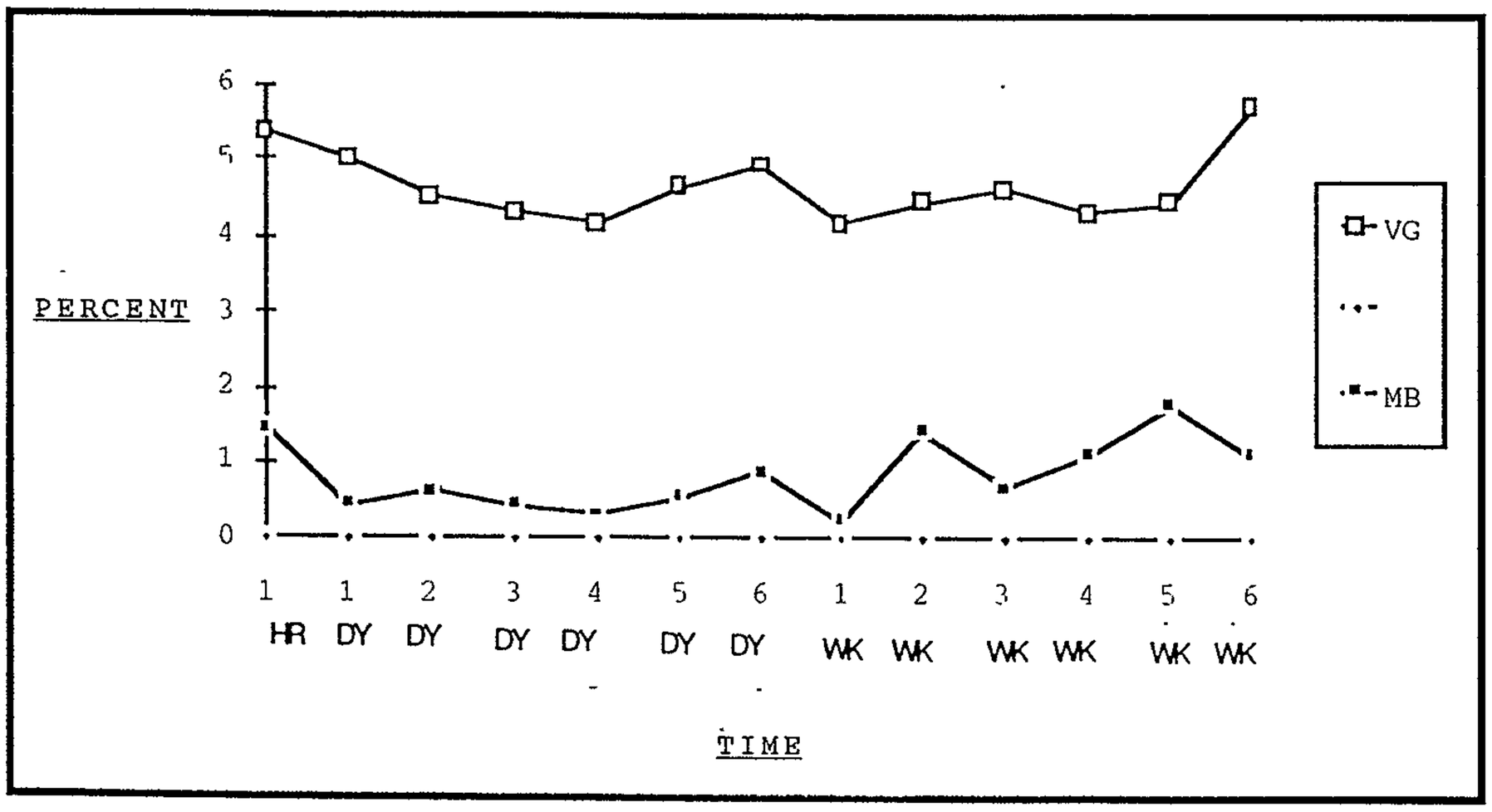

FIGURE 11:PERMANENT DEFORMATION FOR 200G LOADING

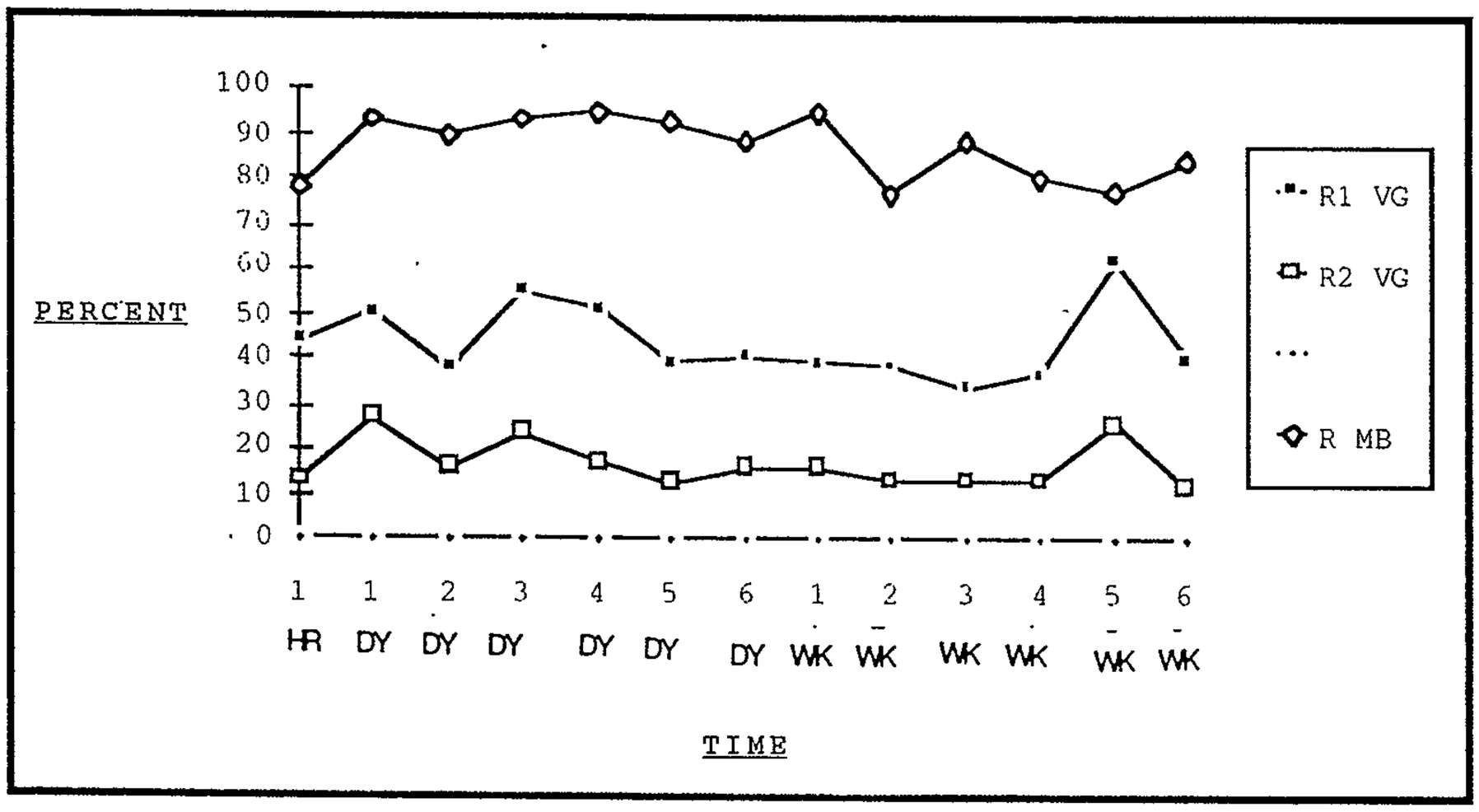

FIGURE 12:ELASTIC RECOVERY FOR 200G LOADING

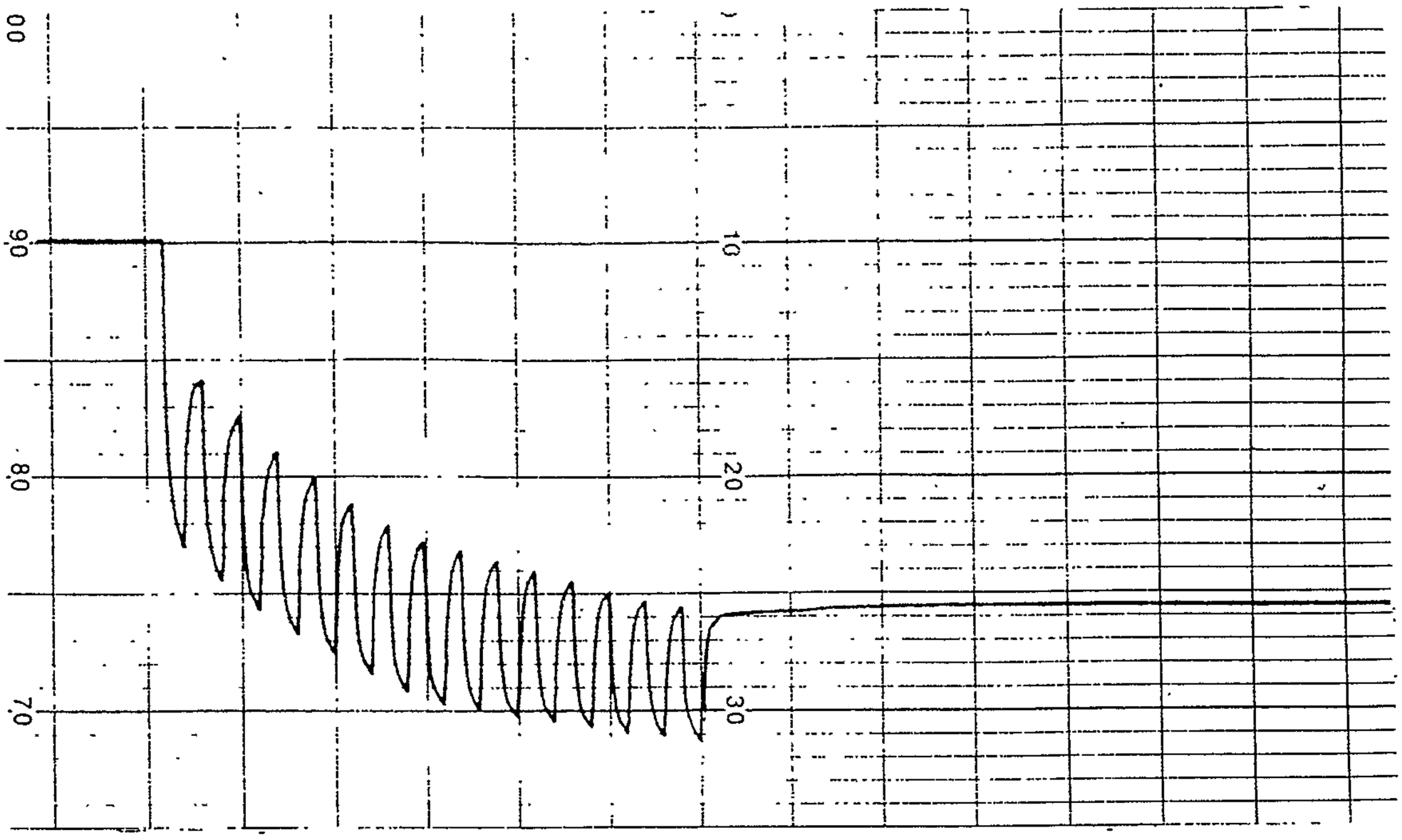

FIGURE 13: TRACE OF VISCO-GEL

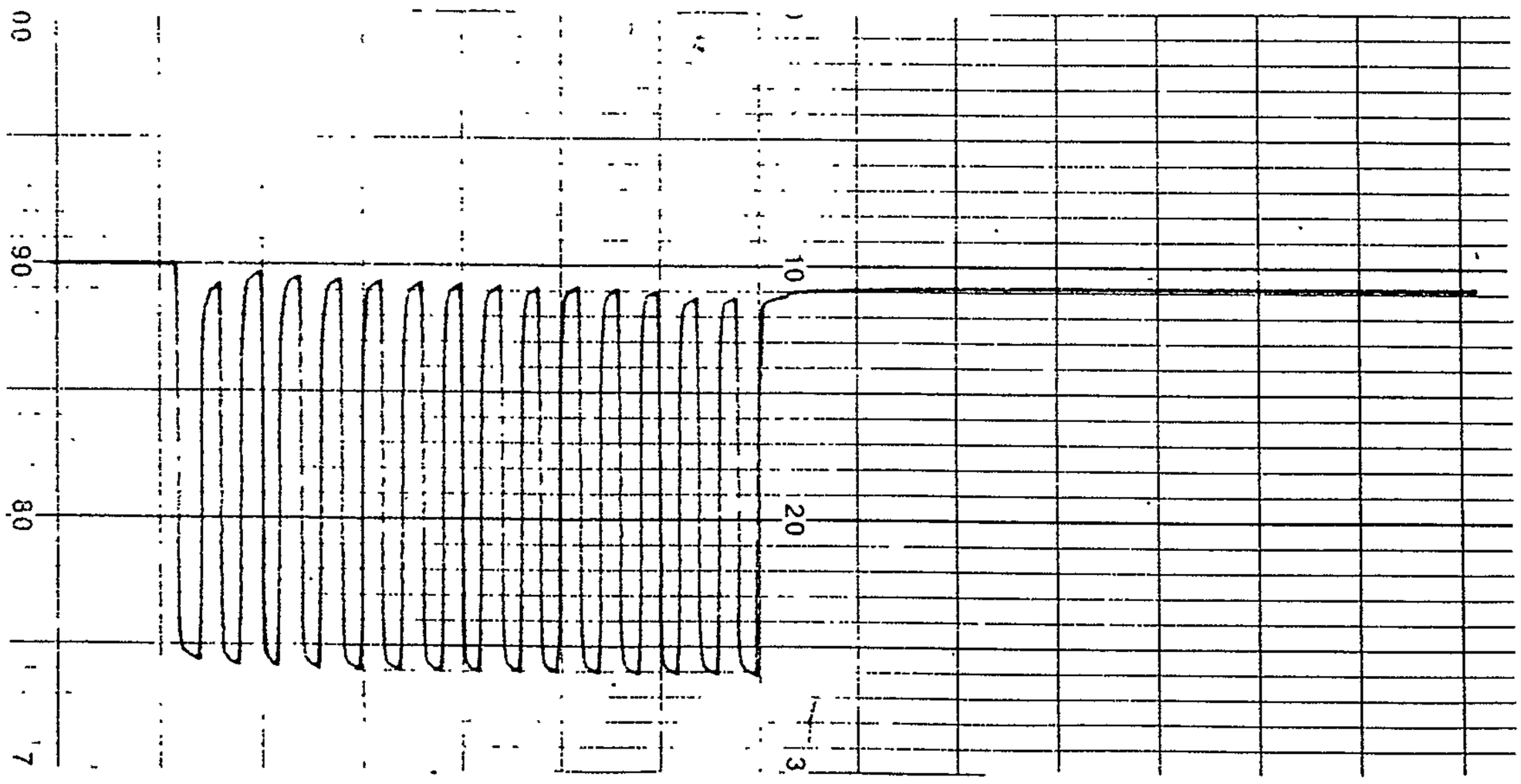

FIGURE 14 TRACE OF MB

CHAPTER 4

DISCUSSION

4.1 Thickness measurement

4.1.1 Visco-gel

The inherent stickiness and porosity formation were the two major problems in the test of VG. In particular the 1 hour specimens were often distorted as it became necessary to pry them loose from both the mold and the glass cover. Robinson and McCabe (1982) solved a similar problem in their study by using a tin foil mould liner. The thickness variations at 1 hour were greatly reduced by day 1 (Figure 4). This is probably a result of the first loading which ironed out the irregularity in the shape. Even so it does not appear possible to maintain a perfectly flat specimen as they all exhibited slump during the storage as will be discussed later. Robinson and McCabe (1982) found problems with "flash" on removal of the specimens from their mold which prevented the specimens from being perfectly flat. To rectify this they pre-loaded the specimens at 54 g/cm^2 for 30 seconds and then zeroed the gauge.

The present study attempted to achieve some uniformity in thickness measurement by taking readings after 1 minute for VG. The measuring load of 25 g (2.5 g/cm^2) was much lower than that used in the cyclic test (3.8 g/cm^2). As the latter load generally showed a flat base line (A_0 to A_1 in Figure 8), it appears to be ideal for eliminating inaccuracies in thickness readings without imposing excessive compressive forces on the specimen. Furthermore

the wide cross-sectional area used contributed to obtaining this flat pre-loading base line.

The thickness measurements for VG were affected by the phenomenon of "slump". Starke et al. (1972) allowed unstrained specimens of a VG-like material to stand freely in a humidifier for 24 hours and found that the material underwent a steady and gradual slump under its own weight. Robinson and McCabe (1982) found that after less than 24 hours storage Coe Soft (a similar material to VG) had started to flow under its own weight and to conform to the shape of the container in which it was stored. The plastic containers used for the present study had a slightly raised area in the centre of the base and towards the end of the study the VG specimens had taken on this shape. In future studies it may be wise to use containers with perfectly flat bases.

To eliminate some of the adherence problems in the 1 hour specimens it is important to establish a protocol for determining the exact setting times of the materials before testing. This study relied on manufacturer's recommendations regarding time taken for the material to set. More accurate methods such as the use of a reciprocating rheometer to monitor viscosity changes of the materials (Wilson et al. 1966; DeMot et al.1984) or the resistance to penetration by an indentor in a Shore A durometer test (Starke et al.1972) may prove more accurate.

Another means of eliminating adherence problems would be by using a tin-foil surface separator. Robinson and McCabe (1982) used a 0.001 mm thick lining on their

specimens and found that it not only eliminated the adherence problem, but also allowed stress free removal of the specimens from their mold.

4.1.2 Molloplast B

The adhesive and porosity problems encountered with VG did not occur in the test of MB specimens. The thickness was stable from 1 hour up to and including the 6 weeks There was no obvious trend in thickness changes thereby supporting the work of Braden and Wright (1983) who showed MB to be dimensionally stable on storage in water.

4.2 Mass measurement

4.2.1 Visco-gel

All VG groups maintained a constant mass over the six week period. Both control and tested specimens displayed the same trends, thereby suggesting that the stressing of the specimens had negligible effect on the mass. Since the values for mass are an average of five specimens it would be expected that the initial values for 100g, 200g and 400g would be similar, but problems in initial specimen preparation (excess porosity and adherence) resulted in large differences between the 100g specimens and the 200g and 400g specimens.

The nett result of sorptive processes is usually a weight loss (Braden and Causton 1971, Starke et al. 1972) as the lighter water molecule replaces the heavier ethanol and dibutyl molecules.

In this study there were two factors that altered this process. Firstly, storage conditions. In the present study, amongst others (Travaglini et al.1960, Craig and Gibbons 1961, Eick et al.1962, Bates and Smith 1965) the

specimens were stored in the one solution of distilled water for the duration of the experiment. An equilibrium will thus be reached where absorption is equal to desorption. At this point the solution may be saturated with plasticisers and ethanol, which themselves may start to re-enter the specimen. Therefore predicted dimensional changes could not be expected. This is not a situation that can arise in the mouth where the leached products are either swallowed with saliva or thrown out with the denture cleanser. Storer (1962) tried to simulate these conditions in his experiment by storing the specimens in running water.

The second factor in weight analysis of VG was the varying degrees of porosity in the specimens. For future studies, to minimise this problem it would be better to mix the materials

under vacuum, and then allow the material to set in a hydroflask (Davenport et al. 1986).

4.2.2 Molloplast B

MB has a low water absorption and reaches equilibrium relatively quickly (Wright 1976, Wright 1981) as shown by the virtually straight line graph for mass changes of the material.

4.3 Rheological models

Elastic properties are often defined in terms of the ability of a material to undergo elastic recovery. When a material undergoes full elastic recovery after removal of an applied load it is elastic. If the recovery takes place slowly, or if a degree of permanent deformation remains,

the material is said to be viscoelastic. Models involving the use of springs and dashpots can be used to explain the elastic and viscoelastic behaviour of materials. When a spring, which represents an elastic material, is fixed at one end and a load is applied at the other it becomes instantaneously extended. When the load is removed it immediately recovers its original length. When a load is applied to a dashpot, which represents a viscous material, it opens slowly, strain being a function of the time for which the load is applied. When the load is removed the dashpot remains open and no recovery occurs.

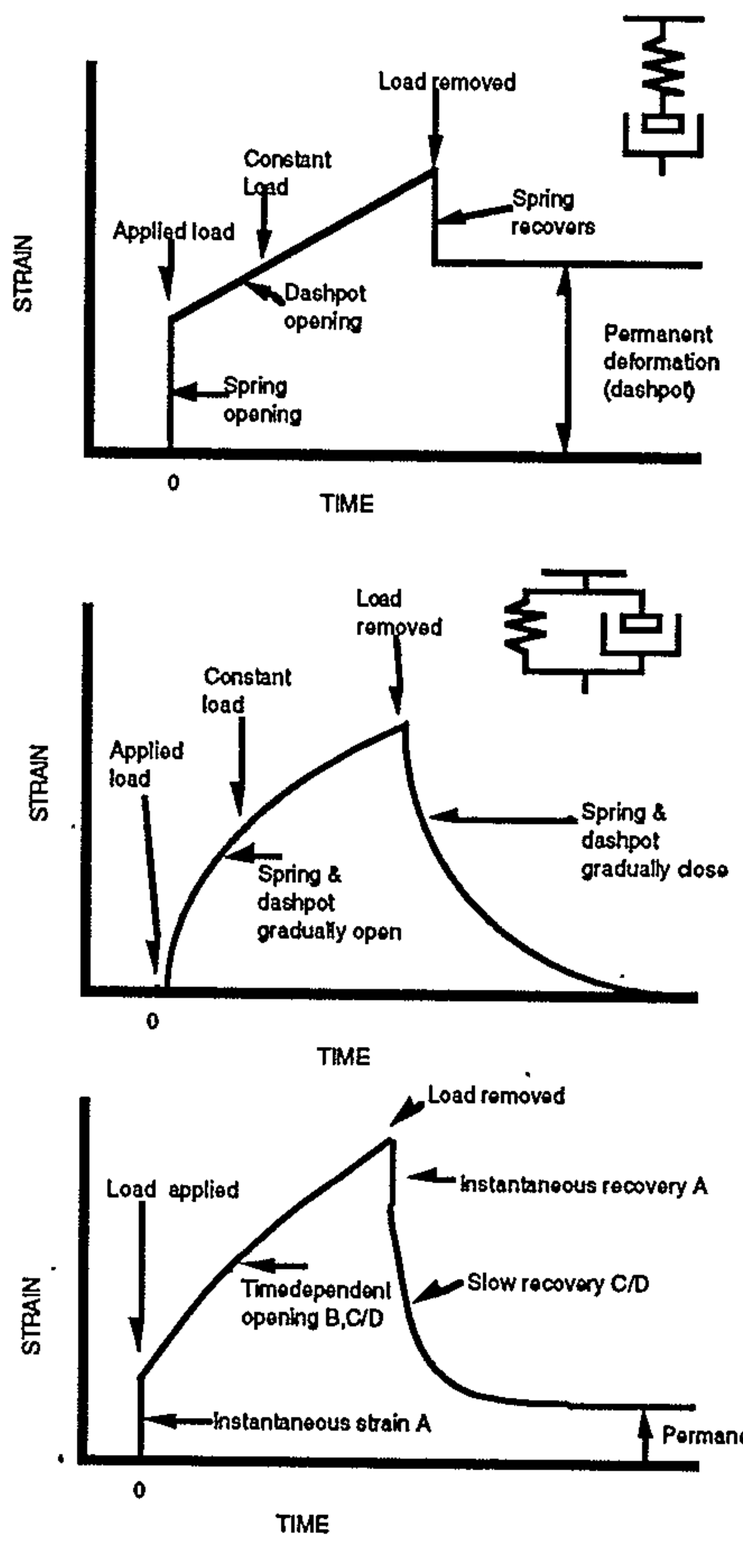

FIGURE 15: MAXWELL MODEL

FIGURE 16: VOIGT MODEL

FIGURE 17: COMBINATION MODEL

For the material behaving as a spring and dashpot in series, referred to as a Maxwell model (Figure 15), application of a load causes the spring to be extended instantaneously followed by slow opening of the dashpot. On removal of the load the spring recovers but the dashpot remains permanently open. The magnitude of the opening depends on the applied load and the time for which the load is applied.

For the material behaving as a spring and dashpot in parallel, referred to as a Voigt model (Figure 16), application of load causes slow opening of the spring under the dampening effect of the dashpot. Following removal of the load the dashpot and spring slowly recover to their original state under the elastic influence of the spring and the damping influence of the dashpot. The time taken to recover is a function of the applied load and the time of application of the load.

Many materials used in dentistry behave like a combination of the Voigt and Maxwell models (Figure 17). Such materials show an instantaneous increase in strain due to the spring, followed by an increase in strain as the dashpot and spring/dashpot system opens. On removal of the load the spring recovers instantaneously followed by gradual recovery of the spring/dashpot (represented by both E and R indices). Some permanent distortion remains as a consequence of the dashpot (represented by the P index). Again the magnitude of the permanent deformation is a function of the applied load and the time of application.

4.4 Rheological changes of Visco-gel

Due to the loose structure of VG it would be expected that the response to loading would be viscoelastic and that both the storage and loading conditions would affect this rheological response. In fact the trace for VG (Figure 8) is very similar to the combination of Maxwell and Voigt graphs shown in Figure 17.

The rapid development of elasticity over the initial 24 hours spoken of in previous studies (Braden 1970; De Mot et al.1984; Graham et al.1990) was shown in the present study by both the E_1 and E_2 values which increased considerably from the 1 hour to 24 hour results (Figure 10). Thereafter both responses never varied more than 1 percent. An interesting point from this graph is the way the E_2 results follow the E_1 results, only at a reduced level. This is again shown in the comparison between R_1 and R_2 (Figure 12) where the values for R_2 were consistently lower than those of R_1. This is likely to be the result of the specimen absorbing part of the stress as permanent deformation on each cycle, and therefore not recovering the full amount. The consistency in both E and R indices for the 6 week period reflects the equilibrium conditions existing in the storage solutions.

The 200g specimens show an early decrease in plastic deformation which is consistent with the formation of the gel structure and early loss of ethanol (Ellis et al.1980). Thereafter the percentage deformation remains quite constant until the end of the study as ethanol and plasticiser desorption is balanced by water absorption. The third phase in the structural development of the

material (Section 1.5) where most of the ethanol and plasticiser have been lost and the specimen has become quite rigid did not show in this study probably because the solution remained the same throughout the six week period. Ellis et al.(1979) showed that not all of the ethanol had diffused out of the soft liner he investigated after four and three-quarter months. It seems therefore that a much longer experimental time would be needed to demonstrate the development of this phase. I do not think that the load itself had a pronounced effect on the specimen's viscoelastic development.

4.5 Rheological changes of Molloplast B

Given the fact that MB is normally quite stable in water we would not expect any of the indices, that is the permanent deformation, the elastic response or the elastic recovery, to vary a great deal over time. This was shown by the results of this study in the basically unchanging graphs. Any variations are probably more due to the testing procedure than changes within the material itself.

Overall however, R and E graphs give a clear indication of the elasticity of the material. The representative trace (Figure 9) bears close resemblance to the Maxwell model graph (Figure 15). The P graph shows that the amount of permanent deformation was under 1 percent while the graph for R shows that the specimens consistently recover about 90 percent of their thickness. An interesting section of the graph for E occurs from week 2 to week 6. Studies by Duran et al.(1979) and Braden and Wright (1983) showed that the compliance of MB increased

when stored in water. The mentioned trace may be the start of this process. Braden thought that perhaps this phenomenon was the result of absorbed water disturbing the molecular integrity of the material. The more compliant the material becomes the more it is going to deform on each loading/unloading cycle. This is shown by a corresponding increase in average deformation over the aforementioned period. The material becomes softer, but does not lose its elasticity. Therefore the cross-linkages between molecules are interrupted but not destroyed.

4.6 Liners and the importance of rheological conditions.

Given these two extremes of liners, the question arises as to which of them makes the better material, and which has the most desirable properties. Most of the studies treat denture liners and tissue conditioners as two separate types of materials. Therefore suggestions as to desirable properties generally follow two lines of thought (Section 1.8). We are therefore confronted by the dilemma of what the ratio between elasticity and viscosity should be for a lining material.

For a material to be successful I do not think that it can act as both a tissue conditioner and a long term soft liner. If attempting to either make a new denture, or rebase an existing one, there are two options open to us. Either, the denture could be removed from the mouth (Lytle 1959), or alternately a tissue conditioner could be used to allow complete healing prior to any procedure. The tissue conditioner is used purely as an interim measure. If a denture liner is to be used it is incorporated into

the new denture and should possess the following characteristics:

1. Predominantly elastic behaviour to absorb the stresses produced in the mouth, but also with some flow potential. This flow is not to be used to counter occlusal discrepancies (Duran et al.1979), nor to change the shape of the base to counter inflammation of the tissues. Rather it should only flow enough to account for age changes in both the bone and mucosa/submucosa. Since these changes are very slow in the absence of pathological processes, the amount of flow should be correspondingly small. This is perhaps an unrealistic condition since it would be impossible to formulate a liner that could adapt individually for each patient and each situation over an extended time frame. Materials such as Visco-gel that are able to fulfil this requirement are only able to do it in the short term. Unfortunately their rheological profile of small instantaneous elasticity followed by a large delayed deformation do not allow an optimum thickness of 3 mm to be maintained over time (Kawano et al.1991). Molloplast B on the other hand would be able to maintain its thickness because of its inherent elastic nature, but would not be able to adapt to subtle tissue changes.

2. The material should be soft and compliant so not to traumatise the denture supporting tissues, and this softness must remain over the lifetime of the liner and not progressively harden. As was explained in Section 1.4, this concept of "softness" is really a generalised term which does not imply any particular rheological behaviour. It is possible for an elastic material to be soft or hard, and similarly for a viscoelastic material to be soft or

hard. Once a rheological test confirms that the material is elastic, the softness relative to other elastic materials can be determined by the use of a durometer. Shore Durometer readings ranging from 36 to 78 (mean 55.8) have been reported for Mollplast B (Schmidt and Smith 1983) which appears to be too hard. Wilson and Tomlin (1969) compared the softness of seven different types of liners using an indentation test and found Molloplast B to be the second hardest. On interaction with fluid however some softening of the material could be expected (Duran et al.1979; Braden and Wright 1983). De Mot et al.(1984) compared the compression softness of four tissue conditioners and found Visco-gel to have ideal cushioning effect but only if used over short time periods. Suggestions have been made that gradual hardening of soft liners is a desirable feature because it conditions the oral mucosa to being able eventually to accept an acrylic denture (Braden and Wright 1983). I do not see this concept as being pertinent in this situation because the soft liner is not going to be replaced. This softness will assist from both a psychological and functional point of view.

3. An ideal material will contain no soluble material and have a low water absorption thereby reducing dimensional changes (Braden and Wright 1983) Alternately it may be possible to confine these components within the material so as to maintain the original properties for a relatively longer time even under loading conditions as was shown in the present study. It may be possible to coat materials such as Visco-gel to prevent the loss of soluble components (Szabo et al.1986).

CHAPTER 5

SUMMARY AND CONCLUSIONS.

The aim of this project was to investigate the rheological testing of denture lining materials and to clarify the terminology related to these materials. The apparatus and procedure attempted to utilise both the dynamic and compressive creep elements of previous studies. Specimens of Molloplast B (a heat and pressure cured silicone) and Visco-gel (a self-curing polymer-gel acrylic) were tested under the simulated oral conditions of 37^0C in a water bath. These lining materials were chosen on the basis that they are widely used in dental practice and have been shown in earlier studies to exhibit contrasting rheological behaviour. Five specimens of each material were tested under three different loads: 100 g, 200 g and 400 g. One specimen served as a control. The thickness changes, weight changes and rheological characteristics of both materials were compared over a six week period.

The following conclusions have been drawn and recommendations made:

1. For self-curing materials such as Visco-gel it is important to pre-determine setting times. Those recommended by the manufacturer may not be ideal in a given set of circumstances.

2. The stickiness of Visco-gel makes stress free removal from both the mould and storage containers difficult. Some form of separator such as a silicone spray or metal foil therefore needs to be applied to the surface.

3. Visco-gel should be mixed under vaccuum and allowed to cure in a hydroflask to reduce the porosity problems associated with hand-mixing procedures. However, if clinical conditions are to be emulated then handmixing should be acceptable.

4. The dimensions of the specimens (10 cm^2 x 3 mm) and the pre-loading mass of 38 g (3.8 g/cm^2) were ideal to give a flat pre-loading trace. The thickness of 3 mm followed clinical recommendations.

5. There is a need to review storage conditions. In the present study the distilled water was not changed for the duration of the experiment. Values for thickness, mass and rheological indices remained quite constant throughout the six week period. This is not realistic given the fact that in the clinical situation there is a continual turnover of saliva and other fluids. Realistically it would have been better to have changed the storage solutions daily.

With the development of ion exchange chromatography it whould be possible to monitor each specimen's solution daily if you were interested in monitoring the loss of volatile substances from the specimens. This procedure could be carried out at the same time as the measuring of weights and thickness. These findings would be correlated with weight and thickness changes, and variation in rheological behaviour. These observations could be made until such a time as an equilibrium has developed between the absorptive and desorptive processes. At this time the solution could be discarded, new distilled water placed, and readings commenced again.

Instead of distilled water it would be beneficial to

use artificial saliva as the behaviour of liners has been noted to vary between the two solutions.

6. Thickness and weight changes for Molloplast B specimens over the 6 week period were negligible. Neither the loading nor storage conditions appeared to affect the dimensional stability of the material.

7. Weight changes for Visco-gel were minor and probably the result of sorptive processes. Thickness changes were more varied reflecting an interaction between sorptive processes, the effect of the applied load, slump of the material and problems with the specimen preparation protocol.

8. The problems encountered with both the specimen preparation protocol and the testing procedure were almost exclusively limited to the 100 g and 400 g loads. Therefore the 200 g specimens were analysed for rheological properties.

9. The amount of permanent deformation in the Molloplast B specimens was generally under 1 percent and the average deformation in each testing cycle was around 6 percent. These percentages were an averaged response of the five tested specimens per load, and calculations were based on the pre-testing thicknesses of each specimen. This average deformation was constant throughout each testing cycle. This fact along with the low value for permanent deformation implies that the material is predominantly elastic. There were slight changes towards the end of the study in the rheological response of the material when the specimens became more compliant, probably as a result of water disrupting the ordered structure of the material.

10. For Visco-gel the permanent deformation remained

around 4.5 percent. The recovery at the end of cyclic loading was always much smaller than the initial recovery, with both values showing a decreasing trend over the 6 week period. The higher permanent deformation value for Visco-gel along with a decaying elastic response both within the same testing cycle and over time implies that the material exhibits some flow properties and is therefore viscoelastic.

11. The lack of internationally accepted standards for lining materials has led to some confusion in the terminology used to describe them. The terms "resilient" and "soft" represent totally different concepts in rheology, yet are used to describe the same materials. The term "resilient" if used correctly describes quite a strict set of conditions and behaviour. The term "soft" on the other hand is a very general concept. Neither term can accurately encompass the wide variety of rheological behaviour displayed by the numerous lining materials, as was shown in the present study. Therefore no rheological adjectives should be used to describe denture liners, instead this phrase should stand on its own. If an adjective is needed to separate the hard acylic liners from the softer rubbers or acrylics, then a more general term such as "soft" should be employed.

12. An ideal lining material would have predominantly elastic behaviour to absorb the stresses produced in the mouth, while being soft at the same time . Molloplast B has ideal elastic properties but is too hard. This would result in some discomfort because of stresses being transferred to the underlying tissues. Visco-gel is soft enough but flows too much. This would result in changes in

the vertical dimension of the denture and a reduction in the thickness of Visco-gel necessary to be effective. These properties need to be retained over the lifetime of the liner. A new material therefore needs to be developed that has no interaction with the oral environment or a coating found to seal lining materials so as to prevent the loss of components which would affect their properties.

13. During the present study a method was developed in which a material may be tested to determine whether it satisfies the requirements of being an adequate lining material.

APPENDICES

TABLE 1: THICKNESS VARIATIONS FOR VISCO-GEL

TIME	100G	SD	CONTROL	200G	SD	CONTROL	400G	SD	CONTROL	CONTROL MEAN	SD
1 HR	3.26	0.05	3.17	3.09	0.06	3.63	3.03	0.06	3.19	3.33	0.26
1 DAY	3.12	0.11	3.20	3.10	0.06	3.48	3.10	0.09	3.19	3.29	0.17
2 DAYS	3.07	0.10	3.26	3.09	O.04	3.49	3.10	0.04	3.22	3.32	0.14
3 DAYS	3.07	0.06	3.19	3.14	0.05	3.47	3.09	0.07	3.18	3.28	0.17
4 DAYS	3.04	0.07	3.04	3.12	0.09	3.42	3.07	0.08	3.19	3.22	0.19
5 DAYS	3.05	0.08	3.05	3.17	0.06	3.42	3.08	0.05	3.26	3.24	0.19
6 DAYS	3.01	0.08	3.07	3.12	0.04	3.46	3.13	0.09	3.23	3.25	0.20
1 WEEK	3.05	0.09	3.07	3.10	0.04	3.39	3.10	0.06	3.20	3.22	0.16
2 WEEKS	3.12	0.10	3.07	3.12	0.04	3.38	3.10	0.05	3.20	3.22	0.15
3 WEEKS	3.15	0.08	3.29	3.17	0.06	3.36	3.10	0.03	3.37	3.34	0.04
4 WEEKS	3.13	0.06	3.15	3.20	0.03	3.36	3.17	0.03	3.33	3.28	0.11
5 WEEKS	3.12	0.09	3.12	3.17	0.03	3.32	3.10	0.08	3.35	3.26	0.12
6 WEEKS	3.17	0.06	3.13	3.15	0.05	3.29	3.10	0.03	3.29	3.24	0.09

TABLE 2: THICKNESS VARIATIONS FOR MOLLOPLAST B

TIME	100G	SD	CONTROL	200G	SD	CONTROL	400G	SD	CONTROL	CONTROL MEAN	SD
1 HR	3.40	0.14	3.39	3.38	0.06	3.36	3.43	0.08	3.49	3.41	O.O7
1 DAY	3.45	0.12	3.39	3.42	0.06	3.50	3.42	0.05	3.45	3.45	0.05
2 DAYS	3.45	0.13	3.44	3.43	0.06	3.43	3.43	0.07	3.27	3.38	0.09
3 DAYS	3.45	0.09	3.43	3.49	0.08	3.43	3.41	0.06	3.34	3.40	0.05
4 DAYS	3.46	0.10	3.45	3.49	0.08	3.48	3.45	0.07	3.31	3.41	0.09
5 DAYS	3.46	0.11	3.45	3.43	0.05	3.38	3.42	0.08	3.32	3.38	0.07
6 DAYS	3.44	0.11	3.43	3.44	0.10	3.39	3.41	0.07	3.36	3.39	0.04
1 WEEK	3.45	0.13	3.39	3.41	0.07	3.50	3.43	0.04	3.30	3.40	0.10
2 WEEKS	3.47	0.09	3.40	3.39	0.07	3.40	3.38	0.05	3.27	3.36	0.07
3 WEEKS	3.44	0.10	3.37	3.44	0.06	3.45	3.45	0.07	3.39	3.40	0.04
4 WEEKS	3.45	0.11	3.41	3.40	0.08	3.42	3.42	0.08	3.32	3.38	0.05
5 WEEKS	3.49	0.11	3.38	3.44	0.10	3.45	3.45	0.07	3.34	3.39	0.06
6 WEEKS	3.49	0.11	3.37	3.44	0.04	3.47	3.46	0.07	3.37	3.40	0.06

TABLE 3:MASS VARIATIONS FOR VISC0-GEL

TIME	100G	SD	CONTROL	200G	SD	CONTROL	400G	SD	CONTROL	CONTROL MEAN	SD
1 HR	3.35	0.03	3.31	3.4	0.03	3.48	3.40	0.01	3.41	3.40	0.08
1 DAY	3.36	0.03	3.33	3.4	0.03	3.48	3.40	0.01	3.41	3.41	0.08
2 DAYS	3.36	0.03	3.31	3.4	0.03	3.49	3.41	0.02	3.40	3.40	0.09
3 DAYS	3.34	0.03	3.30	3.39	0.03	3.47	3.38	0.01	3.39	3.39	0.09
4 DAYS	3.34	0.03	3.30	3.38	0.03	3.48	3.38	0.01	3.39	3.39	0.09
5 DAYS	3.34	0.03	3.30	3.38	0.03	3.47	3.38	0.01	3.39	3.39	0.09
6 DAYS	3.34	0.03	3.29	3.38	0.03	3.48	3.38	0.01	3.42	3.40	0.09
1 WEEK	3.34	0.03	3.30	3.37	0.03	3.47	3.38	0.01	3.37	3.38	0.09
2 WEEKS	3.33	0.03	3.30	3.37	0.03	3.47	3.37	0.01	3.38	3.38	0.08
3 WEEKS	3.33	0.03	3.29	3.36	0.03	3.47	3.37	0.02	3.38	3.38	0.09
4 WEEKS	3.34	0.03	3.30	3.37	0.03	3.47	3.38	0.01	3.38	3.39	0.09
5 WEEKS	3.33	0.03	3.29	3.37	0.02	3.47	3.37	0.01	3.38	3.38	0.09
6 WEEKS	3.33	0.03	3.29	3.36	0.03	3.48	3.37	0.01	3.38	3.38	0.10

TABLE 4: MASS VARIATIONS FOR MOLLOPLAST B

TIME	100G	SD	CONTROL	200G	SD	CONTROL	400G	SD	CONTROL	CONTROL MEAN	SD
1HR	3.54	0.15	3.54	3.49	0.08	3.45	3.50	0.05	3.49	3.49	0.05
1 DAY	3.53	0.15	3.53	3.48	0.09	3.41	3.50	0.05	3.47	3.47	0.06
2 DAYS	3.55	0.15	3.52	3.49	0.08	3.40	3.50	0.05	3.47	3.47	0.06
3 DAYS	3.53	0.16	3.52	3.49	0.09	3.41	3.50	0.05	3.47	3.46	0.05
4 DAYS	3.53	0.15	3.52	3.49	0.08	3.40	3.50	0.05	3.47	3.46	0.06
5 DAYS	3.55	0.15	3.52	3.49	0.09	3.41	3.50	0.05	3.47	3.46	0.06
6 DAYS	3.54	0.15	3.52	3.49	0.09	3.41	3.50	0.05	3.47	3.46	0.06
1 WEEK	3.53	0.16	3.51	3.49	0.09	3.41	3.50	0.05	3.47	3.46	0.05
2 WEEKS	3.53	0.16	3.52	3.49	0.08	3.42	3.53	0.09	3.48	3.47	0.05
3 WEEKS	3.54	0.16	3.52	3.49	0.09	3.42	3.52	0.05	3.52	3.49	0.05
4 WEEKS	3.54	0.16	3.53	3.51	0.09	3.43	3.53	0.05	3.50	3.48	0.05
5 WEEKS	3.55	0.15	3.54	3.49	0.09	3.41	3.51	0.05	3.47	3.47	0.07
6 WEEKS	3.54	0.15	3.54	3.40	0.08	3.43	3.51	0.06	3.48	3.48	0.05

TABLE 5: RHEOLOGICAL INDICES FOR VISCO-GEL

	100G									
TIME	P	SD	E1	SD	E2	SD	R1	SD	R2	SD
1 HR	9.92	4.32	1.55	0.92	0.83	0.35	25.81	13.88	8.82	5.11
1 DAY	4.74	1.06	1.89	0.44	0.83	0.35	42.89	6.38	19.04	2.77
2 DAYS	4.89	1.32	1.66	0.72	1.11	0.50	37.10	6.38	17.35	3.21
3 DAYS	3.35	1.72	1.28	0.26	0.94	0.10	46.97	18.03	24.86	12.41
4 DAYS	2.36	0.65	1.24	0.37	0.97	0.32	48.53	3.83	26.81	6.12
5 DAYS	3.14	2.06	1.12	0.28	0.94	0.22	46.67	4.29	26.48	2.25
6 DAYS	2.31	0.51	1.06	0.16	0.82	0.10	50.91	2.91	25.27	3.18
1 WEEK	2.76	0.95	1.10	0.54	0.92	0.47	32.48	20.90	23.98	10.31
2 WEEK	3.82	0.87	2.05	0.42	1.10	0.21	54.44	3.36	20.90	3.32
3 WEEK	1.95	0.85	0.94	0.28	0.71	0.27	58.49	17.01	27.54	12.48
4 WEEK	2.05	0.51	0.74	0.24	0.59	0.21	47.37	12.46	22.31	7.71
5 WEEK	3.10	0.68	0.53	0.35	0.41	0.20	32.19	20.09	11.98	6.89
6 WEEK	2.50	0.78	1.08	0.34	0.60	0.32	63.78	16.51	23.91	8.28

	200 G									
TIME	P	SD	E1	SD	E2	SD	R1	SD	R2	SD
1 HR	5.40	0.98	2.03	1.13	0.90	0.51	44.32	14.49	13.43	5.19
1 DAY	5.03	0.94	2.43	1.00	1.99	0.71	50.39	18.02	27.27	9.02
2 DAYS	4.53	0.88	1.71	0.58	0.99	0.60	38.44	11.18	16.06	10.54
3 DAYS	4.31	0.87	2.32	0.67	1.83	0.63	55.26	12.77	23.51	12.94
4 DAYS	4.13	0.97	1.92	0.74	0.99	0.58	51.45	12.01	17.24	4.63
5 DAYS	4.65	0.21	1.74	1.03	0.84	0.82	39.32	15.30	12.56	10.39
6 DAYS	4.92	1.74	1.90	1.36	1.16	0.80	40.87	15.98	15.96	6.32
1 WEEK	4.15	0.87	1.31	0.45	0.82	0.50	39.35	8.62	16.08	9,79
2 WEEK	4.43	0.38	1.13	0.30	0.69	0.14	38.58	11.88	13.16	2.68
3 WEEK	4.61	1.29	1.07	0.50	0.71	0.40	33.70	7.20	12.98	6.70
4 WEEK	4.31	1.16	1.65	0.96	0.78	0.25	36.71	12.03	12.97	4.68
5 WEEK	3.45	1.72	1.74	0.96	1.26	0.70	61.98	25.70	25.66	9.64
6 WEEK	5.72	2.06	1.27	0.36	0.56	0.28	40.41	13.07	12.13	9.54

	400G									
TIME	P	SD	E1	SD	E2	SD	R1	SD	R2	SD
1 HR	7.55	0.76	2.31	0.90	1.06	0.47	35.45	13.87	11.41	5.17
1 DAY	8.43	0.83	3.98	1.00	1.97	0.58	55.67	16.40	18.60	5.70
2 DAYS	7.67	1.69	2.05	0.92	0.98	0.11	31.67	4.63	10.03	2.27
3 DAYS	5.30	0.55	1.75	0.63	0.83	0.20	36.04	9.88	11.41	2.74
4 DAYS	6.12	1.48	1.65	0.61	0.88	0.29	33.17	11.54	11.37	3.76
5 DAYS	4.94	1.08	1.78	1.07	1.09	0.54	41.64	19.31	14.51	7.18
6 DAYS	5.53	1.14	1.28	0.14	1.08	0.14	31.80	4.00	13.34	2.54
1 WEEK	7.65	1.43	1.27	0.18	0.83	0.12	27.76	4.83	10.27	1.77
2 WEEKS	7.83	0.95	1.62	0.15	0.90	0.02	28.46	4.05	10.21	0.99
3 WEEKS	4.24	0.50	0.90	0.42	0.46	0.07	36.46	13.76	15.32	7.78
4 WEEKS	5.88	1.50	2.22	1.11	1.56	0.63	48.57	19.74	20.73	6.56
5 WEEKS	5.26	1.31	1.93	0.45	1.31	0.24	46.98	19.96	17.85	8.48
6 WEEKS	8.53	1.64	1.93	0.87	1.13	0.28	32.55	8.81	10.23	1.74

TABLE 6: RHEOLOGICAL INDICES FOR MOLLOLAST B

	100G					
TIME	E	SD	P	SD	R	SD
1 HR	2.99	1.16	1.78	0.83	62.57	12.73
1 DAY	2.72	0.97	2.74	2.94	56.83	23.66
2 DAYS	2.10	0.57	1.68	1.40	60.00	26.78
3 DAYS	2.94	0.86	0.35	0.22	90.26	7.20
4 DAYS	2.92	0.99	0.1	0.23	96.43	5.05
5 DAYS	2.84	0.92	1.14	0.83	72.18	17.91
6 DAYS	2.82	0.59	0.4	0.13	87.62	3.81
1 WEEK	3.18	1.11	0.48	0.38	86.54	10.51
2 WEEKS	3.97	1.66	1.06	1.04	81.57	12.73
3 WEEKS	2.88	1.30	0.11	0.13	96.29	5.40
4 WEEKS	3.10	1.28	0.51	0.49	84.01	16.98
5 WEEKS	2.29	1.33	1.34	1.06	66.95	22.43
6 WEEKS	2.42	1.38	0.43	0.81	84.65	11.24

	200G					
TIME	E	SD	P	SD	R	SD
1 HR	5.21	1.26	1.48	1.84	78.88	20.63
1 DAY	5.99	2.35	0.48	0.57	93.07	8.16
2 DAYS	6.39	2.41	0.65	0.53	89.91	7.63
3 DAYS	5.58	1.46	0.47	0.27	93.15	3.13
4 DAYS	5.99	1.47	0.33	0.19	94.59	3.67
5 DAYS	6.25	1.58	0.54	0.37	92.39	3.70
6 DAYS	6.1	1.72	0.87	0.60	88.38	6.18
1 WEEK	5.78	2.10	0.24	0.33	94.69	4.96
2 WEEKS	4.62	1.22	1.43	0.84	76.65	10.44
3 WEEKS	5.3	0.74	0.68	0.39	88.39	7.37
4 WEEKS	5.55	0.89	1.14	2.38	79.88	20.76
5 WEEKS	5.89	0.99	1.77	0.82	77.21	8.83
6 WEEKS	6.43	1.80	1.14	0.16	84.48	3.28

	400G					
TIME	E	SD	P	SD	R	SD
1 HR	9.21	2.00	1.14	0.70	89.67	5.97
1 DAY	9.59	1.88	0.61	0.53	94.35	4.88
2 DAYS	10.48	2.09	1.02	0.89	90.77	8.49
3 DAYS	9.88	1.85	0.47	0.33	95.70	2.64
4 DAYS	9.36	1.88	0.80	0.63	92.21	6.16
5 DAYS	9.81	2.04	0.56	0.40	94.70	4.60
6 DAYS	9.79	1.47	0.71	0.59	93.38	5.46
1 WEEK	10.84	2.96	1.27	1.82	96.04	3.17
2 WEEKS	8.39	1.17	1.89	1.49	80.49	14.81
3 WEEKS	8.67	2.01	1.44	1.03	85.61	11.07
4 WEEKS	8.77	2.61	3.60	3.04	71.95	23.07
5 WEEKS	9.98	1.92	1.73	0.96	85.33	7.73
6 WEEKS	9.25	1.84	2.21	1.69	80.47	12.23

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