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**A COMPARISON OF FORCE DEGRADATION
CHARACTERISTICS OF CONVENTIONAL
VERSUS
FLUORIDE-RELEASING ELASTOMERIC CHAIN *IN VITRO*.**

By

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ABSTRACT

Fluoride availability to enamel from different sources could be beneficial in prevention of demineralization in orthodontic patients as the fixed orthodontic appliances facilitate plaque retention. Fluoride-releasing elastomeric chain is one of several types of orthodontic material that release fluoride. The objective of this study was to evaluate a comparison of force degradation characteristics of conventional and fluoride-releasing elastomerics *in vitro*. "A"-Company Force-A non-fluoride chain elastic and fluoride-release chain elastic were tested in dry-air and 37° C water over 42 days. Different samples of each type of elastic chain were extended to 16 and 21 mm throughout test period. The tests were repeated under the same experimental conditions.

The elastomeric chains dramatically reduced to approximately 50 percent of initial force after 24 hours activation and the force continuously decreased through to the end of test period. However, there was only small change in force values between 4 week- and 6 week- periods. There were no significant differences in force decay rates for the fluoride releasing and non-fluoride releasing chains at the two amounts of extension in the dry state. However, by the end of the test period under wet conditions, the fluoride chain showed significantly more force decay than the non-fluoride chain. The reduced force value of elastomeric chain in the wet condition was significantly more than that in dry condition after the first hour. There were no differences in force decay rate between the different amounts of extensions.

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This thesis is dedicated to my dear husband, Vichai Ratanayatikul,
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LIST OF ABBREVIATIONS

PUs	polyurethanes
T _m	melting temperature
T _g	glass transition temperature
C	celsius
mV	millivolt
F	fluoride releasing elastomeric chain
NF	non-fluoride-releasing elastomeric chain
D	dry
W	wet
hrs	hours
g	gram
mg	milligram
ppm	parts per million
SD	standard deviation
%	per cent
N	Newton
μg	Microgram
ml	millilitre

INTRODUCTION

Orthodontic fixed appliances complicate cleaning and make access to plaque-retaining areas difficult. There are numerous references in the dental literature to the higher prevalence of dental caries in patients undergoing orthodontic treatment. They have reported in great variety, ranging from 2 to 95% of patients (Mitchell, 1992).

Increasing host resistance is one way to prevent demineralization and caries. It is generally accepted that fluoride is effective in reduction of caries incidence during orthodontic treatment (Landry and Shannon, 1973; Stratemann and Shannon, 1974; Tillery et al., 1976; Hirschfield, 1978; Magness, Shannon and West, 1979; Shannon and West, 1979; Corbett and Shannon, 1980; Ceen 1981; Zachrisson, 1975; O'Reilly and Featherstone, 1987; Ogaard et al., 1988; Geiger et al., 1988).

Visible white spot lesions may develop within 4 weeks- that is, within the period of one orthodontic appointment to the next (Ogaard et al., 1988). Careful inspection of the orthodontic bands and brackets should be carried out at every visit and preventive fluoride programs should be instituted (Zachrisson, 1975). A prevention program has an important role in promoting remineralization in the initial cariogenic process. Incorporating the fluoride ions in elastomerics as a source of fluoride-release is suggested as one way to convey fluoride continuously to saliva if there is regular elastomeric change every 4-6 weeks during extraction space closing stage.

Several types of orthodontic material that release fluoride are effective in decalcification protection, even though some of them release fluoride beneficially only during the first 72 hours (Joseph et al., 1993). Using these materials as an additional fluoride reservoir might be of benefit in decalcification prevention, particularly for those patients with a high caries risk. However, if the fluoride incorporation causes the deterioration of properties of the material, such as decay of

elastic force compared to the conventional material, then the benefit of these modified materials is questionable.

There are several orthodontic force-delivery systems for closing extraction space. Elastomeric chain is one method with the following advantages:

- comfortable and hygienic to the patient.
- requires minimal operator manipulation and chairtime.
- requires minimal patient co-operation.

So elastomeric chain has become popular for closing dental arch spaces.

Fluoride releasing elastomeric chain is a new product. So far, little information exists on it. The general objective of this study is to test the hypothesis that the fluoride incorporation affects the mechanical properties of the elastic chain.

PART I LITERATURE REVIEW

CHAPTER 1

THE ENAMEL DEMINERALIZATION PROBLEM ASSOCIATED WITH ORTHODONTIC APPLIANCES

Fixed orthodontic appliances complicate cleaning and make access to plaque retaining areas difficult. Measurable demineralization could occur as early as 1 month after the initial placement of fixed appliances (O'Reilly and Featherstone, 1987). There has been general agreement that caries is caused by the inter-relationship of microorganism, tooth surface, sugar substrate, time, and host factors (Newbrun, 1980, p.17).

1.1 Initiation and progression of the incipient carious lesion

The acids produced in the plaque dissolve microchannels within the enamel to depths of approximately 20-50 μ . As the carious lesion develops, the loss of mineral results in optical changes, which give the lesion an opaque white appearance, in contrast to the translucence of unaffected enamel. This initial carious lesion is referred to as a "white spot". The surface of such a lesion is hard and resists penetration of an explorer tip. If the lesion continues to progress, the surface will become soft and chalky and cavitation will result (Mellberg et al., 1983, p.21).

1.1.1 Formation of the incipient lesion

The development of the incipient lesion follows the pattern :

- 1) Cariogenic plaque liberates organic acids by fermentation
- 2) If the pH at the enamel surfaces falls to about 5 acid dissolution of the tooth can occur.

3) The pH remains at this level for approximately 20 minutes and then gradually returns to its normal level.

4) Repeated cycles of acid attack result in microscopic demineralization of enamel and the formation of an incipient carious lesion (Stephan, 1948).

The initial stage of development of the carious lesion depends on attack on the enamel by acids produced by plaque bacteria. Two factors involved in this stage are

1) The utility of oral hygiene measures in caries prevention such as mechanical removal of plaque by toothbrushing.

2) The possibilities for therapeutic agents delivered by dentifrice or mouthwash not only to inhibit, but also to help reverse biochemical processes leading to acid-induced lesions.

1.1.2 The demineralization process

The ultimate result of the processes of enamel caries is a dissolution of the mineral phase of the enamel leading to a mechanical failure of the tissue. The early formation of a calcium-deficient apatite is according to the reaction (Berry, 1967 and Ingram, 1983, p.246):



In such material each of the groups is available for exchange with an ion of suitable charge and size. Thus the HPO_4^{2-} groups introduced can be replaced with FPO_3^{2-} or with CO_3^{2-} anions while the hydroxyl group remains available for displacement by fluoride (Ingram, 1983).

Four features of white or brown lesions of dental enamel are i) intact surface, ii) presence of relatively large focal holes, iii) irregular pattern of surface destruction, and iv) prismatic pattern of destruction (Haikel et al., 1983).

Decalcification is defined as loss of calcified tooth substance. It occurs when there is a drop below the critical pH 5 of the oral environment which then favours the diffusion of calcium and phosphate ions out of the enamel (Stephan, 1948).

1.1.3 Remineralization

Remineralization is the process whereby the enamel is repaired. Saliva plays a key role in the process by supplying calcium and phosphate to the tooth surface in sufficient amounts to inhibit demineralization by plaque acids and to reverse or arrest the carious process in its early stages (Backer Dirks, 1966).

1.2 The incidence of decalcification in orthodontic patients

There are numerous references in the dental literature as well as much anecdotal observation about higher prevalence of caries in patients undergoing orthodontic treatment. Wide variation is reported from 2 to 95% (Mitchell, 1992). Dolce (1950) studied caries incidence in relation to orthodontic therapy and concluded that there was not necessarily a great increase in caries due to the presence of orthodontic appliances. Quinn (1956) found that caries could progress under orthodontic bands, but that the progress was slower than in unbanded teeth.

Table 1 Studies of the prevalence of decalcification during fixed orthodontic treatment (whole mouth studies only) (from Mitchell, 1992).

Author	Design	Index used	Prevalence	Comments
Meyers 1952	Longitudinal Direct visual assessment	—	5.8% test teeth 23.8% control teeth	Test teeth treated with varnish prior to band placement
Zachrisson and Zachrisson (1971)	Longitudinal Direct visual assessment	Caries index (Fehr, 1961)	89% patients	Fluoride mouthrinse used during ortho.
Stratemann and Shannon (1974)	Direct visual assessment with photos	—	58% of patients without fluoride 2% of patients on fluoride regime	Comparison of prevalence in orthodontic patients with or without fluoride gel regime
Zachrisson (1977)	Longitudinal Direct visual assessment	'New white spots' noted	15% patients	Fluoride mouthrinse used during ortho.
Gorelick <i>et al.</i> (1982)	Direct visual assessment at end of treatment	Presence (and severity) or absence of white spots	50% patients 11% teeth	
Mizrahi (1982, 1983)	Cross-sectional Direct visual assessment. In small sub-group photos used as well	Scored white opacities (after Curzon and Spector (1975))	84% of patients after ortho. 72% of patients prior to ortho.	
Artun and Brobakken (1986)	Cross-sectional. Direct visual assessment	Caries Index and Gorelick's Index	59% of patients after ortho. 45% of patients not requiring ortho.	Fluoride mouthrinse used during ortho.
Geiger <i>et al.</i> (1988)	Gorelick <i>et al.</i> (1972) used as baseline. Direct visual assessment	Gorelick's Index	34% of patients. 7.5% of teeth	Fluoride programme.
Øgaard (1989)	Cross-sectional. Direct visual assessment	Gorelick's Index	95% of patients 5-7 years after ortho. 85% non-orthodontic controls.	Fluoride mouthrinse used during ortho.
Sonis and Snell (1989)	Scored at end of treatment by direct visual assessment	After Mizrahi (1982)	13% of teeth with conventional adhesive 0% of teeth with Fluoride adhesive	Comparison of 2 adhesives with and without fluoride.

CHAPTER 2

THE ROLE OF FLUORIDE IN CARIES PREVENTION

Caries is caused by the presence in dental plaque of bacteria which can metabolise dietary sugar and thereby produce acids that attack the calcium phosphate mineral comprising the teeth. Early in the carious process a depletion of elements essential to enamel integrity occurs, as well as a preferential removal of calcium. Surface enamel is disrupted and minerals are released first from the surface and later from below the surface. Eventually, an apparently intact but porous surface is established, overlying an area of active demineralization. This area is observed as a "white spot" lesion. Continued demineralization of the lesion leads to a full-blown cavity.

Facilitating increased host-resistance is one way to prevent demineralisation and caries. The other two are plaque removal and diet control.

It is generally accepted that fluoride is effective in the reduction of caries incidence during orthodontic treatment (Landry and Shannon, 1973; Stratemann and Shannon, 1974; Tillery et al., 1976; Hirschfield, 1978; Magness, Shannon and West, 1979; Shannon and West, 1979; Corbett and Shannon, 1980; Ceen 1981; Zachrisson, 1975; O'Reilly and Featherstone, 1987; Ogaard et al., 1988; Geiger et al., 1988).

2.1 History of fluoride

Eager (1901) is credited with first noting a relationship between fluoride and dental caries. In 1916, McKay and Black had reported that mottled teeth appeared to have less caries than teeth not mottled. McCallum et al. (1925) have demonstrated that ingestion of sodium fluoride by rats could result in enamel defects, and later studies (Churchill, 1931) indicated the presence of fluoride in certain waters in endemic fluorosis communities and its absence from or lower concentration in the water of communities of nonendemic areas. Using epidemiological methods, Dean

and associated investigators (Dean et al., 1938, 1939) reported that the incidence of dental caries in communities supplied by fluorine-containing water was significantly lower than that in neighbouring communities with fluorine-free water supplies.

The anti-caries activity of fluoride has been clearly established by clinical and laboratory studies. It is currently considered that fluoride works in several ways and that two major aspects of fluoride action are 1) the inhibition of demineralization at the crystal surfaces, and 2) the enhancement of subsurface remineralization resulting in arrestment or reversal of caries lesions (Ten Cate, 1984; O'Reilly and Featherstone, 1987; Ten Cate and Duijsters, 1983; Ten Cate, 1990).

The caries lesion can hypothetically be prevented, arrested, and or reversed during one or more stages of its development:

- 1) During acid attack on the outermost surface of the enamel prior to the development of any detectable lesion.

- 2) During the initial demineralization process; ie, formation of a white spot (Holmen et al., 1985).

- 3) During white-spot lesion remineralization.

Stage 1 obviously is the preferred site of action of an anticaries regimen or agent, ie., before a detectable lesion has formed. Interference with the caries process at Stage 1 may better be considered prevention as opposed to repair.

It is difficult and probably unnecessary to separate Stages 2 and 3. Depending on the circumstances, they probably are competitive with one another. If conditions favour demineralization, the ability of remineralization processes to prevent or reverse it is reduced. If remineralization is favoured, obviously demineralization is not a problem.

Silverstone (1983) stated that it appears that the initiation of a small sub-clinical lesion in the outer enamel paradoxically aids in preventing its progression, initially, by preferentially taking up more fluoride than adjacent sound enamel. The lesion acts as a fluoride reservoir, and during dissolution, when calcium and phosphate ions are released, fluoride ions within the enamel lesion favour

remineralization. Secondly, if space was not available in the densely calcified tissue, it would not be possible for crystal growth to occur.

2.2 Mode of topical fluoride delivery

There are several ways to convey fluoride to the oral environment :

- a) Water fluoridation
- b) Oral rinse containing fluoride
- c) Fluoride dentifrices
- d) Fluoride tablets
- e) Professionally applied topical fluoride preparations.
- f) Other fluoride topical applications eg. fluoridated salt, fluoride occlusal sealant, fluoride dental floss, etc (Murray, 1986, p.100-115).

Factors important to maximization of fluoride benefits

Several factors have been isolated as important to obtaining the benefits of fluoride. These are (Ericsson, 1980);

- 1) A systemic fluoride supply while the tooth enamel is in the process of mineralization and maturation;
- 2) Contact of the erupted tooth surface and dental plaque with fluoride;
- 3) High frequency of local fluoride application;
- 4) Long duration of the contact with the enamel surface;
- 5) Contact of the newly erupted tooth surface with fluoride;
- 6) Retention of fluoride by the enamel surface;
- 7) Chemical conditions favourable to the formation of fluorapatite.

Of the above, clinical studies support the concept that in the erupted teeth the most important factor in the control of caries by fluoride is the frequency of application of the element to the tooth surface. Systemic fluoride is an important factor

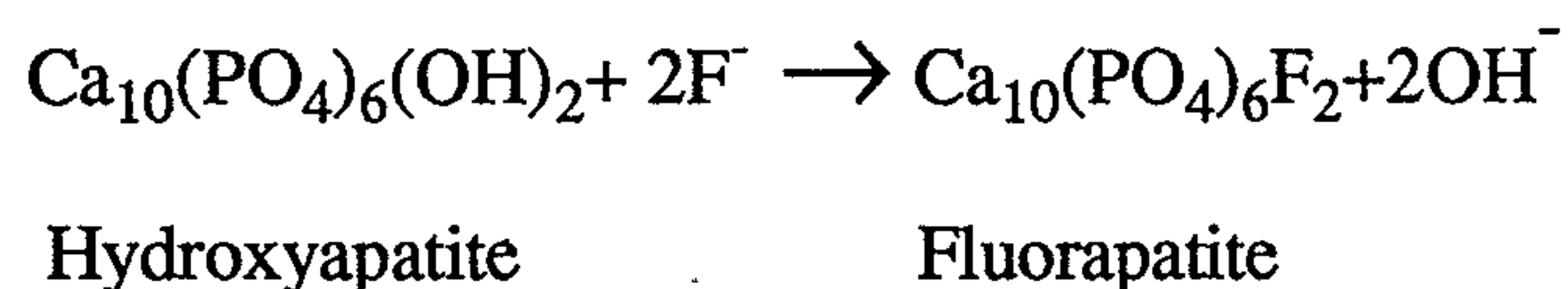
in establishing fluoride effect on teeth pre-eruption; topical fluoride is of major importance post-eruption.

Other side benefits have been reported for fluoride, including improved enamel mineralization and reduced occurrence of hypoplasia after an optimal fluoride regimen, improved tooth alignment, increased resistance to periodontal disease, and reduced sensitivity of exposed dentin (Ericsson, 1980).

2.3 Mechanism of topical fluoride and enamel reaction

When fluoride is applied to an enamel surface it diffuses inward by way of the less dense interprismatic spaces to a depth related to its concentration, the treatment time, pH, and the type of fluoride agent. When the fluoride source is removed and replaced with water or saliva, a large part rapidly diffuses back out (Mellberg et al., 1966), while another part diffuses out more slowly. The fluoride that remains has reacted to form one or more of several compounds, depending on the conditions present.

The presence of fluoride in the dissolution medium effectively reduces the solubility of the enamel by promoting the precipitation of hydroxyapatite and by preventing the formation of more soluble calcium phosphate minerals (McCann, 1953).



It has been proposed that fluoride can interfere with the carious process at three levels: 1) at the level of plaque bacteria, 2) at the surface of the tooth before and during initial acid attack, and 3) during and subsequent to acid attack with lesion formation.

2.3.1 Fluoride and oral bacteria

The inhibitory effect of fluoride on plaque microorganisms has been cited by many investigators (Edgar et al., 1981; Ferretti et al., 1982; Mandell, 1983; Nikiforuk, 1985, p. 58). Saliva from the major salivary glands of subjects ingesting moderate amounts of fluoride contains 0.01-0.03 ppm fluoride. The level of fluoride in saliva is thus too low to affect bacterial metabolism. Fluoride in tongue scrapings ranges from 14-19 ppm and in dental plaque, from 15 to 64 ppm. In plaque, therefore, fluoride concentration can be more than 1000 times that of saliva, clearly indicative of an accumulation of fluoride by plaque. Many investigators have demonstrated fluoride uptake by plaque and the uptake can be quite extensive and is dependent on a fluoride environment (Edgar et al., 1981).

Fluoride acts via its ionic mode. The fluoride ion activity of neutral plaque is only about 2 % of the total plaque fluoride, too low to directly affect plaque bacterial metabolism. On acid challenge, however, fluoride is liberated in ionic form; about 30% or more may become ionized. At these high levels of ionic fluoride, bacterial inhibition as well as remineralization of initial carious lesions becomes possible (Nikiforuk, 1985, p.58). Thus, dental plaque can act as a reservoir for "active" fluoride. With *in vitro* study, slightly higher pH values were obtained following incubation with glucose of organisms previously allowed to accumulate fluoride as compared with organisms not subjected to fluoride (Edgar et al., 1981).

The pH at which ionic fluoride is released from the bound state, pH 6, is the pH at which bacteria are most sensitive to fluoride (Birkeland and Charlton, 1976). Inhibition of acid production by plaque bacteria has been demonstrated at a fluoride level of 1 ppm. Although this is considerably above the concentration of fluoride in saliva, it is much lower than the plaque fluoride concentration potential possible, and when plaque concentration is very high owing to continuous exposure of the plaque to fluoride it is in a "bound" state (Nikiforuk, 1985, p. 58).

Fluoride at an appropriate concentration has been noted to exhibit several effects on bacteria associated with caries, being:

1) Inhibition of enolase activity involved in carbohydrate metabolism, and thus the transport of glucose involving the phosphoenol-pyruvic acid phosphotransferase system. Partial inhibition of enolase occurs at fluoride concentrations of 0.5-1 ppm.

2) Inhibition of phosphatases involved in the degradation of sugar phosphates.

3) Inhibition of potassium transport, involved in carbohydrate metabolism.

4) Decrease in bacterial attachment to surfaces.

5) Increase in uptake of cations such as Sn^{2+} . More tin is accumulated in the presence of fluoride than in its absence (stannous fluoride versus stannous chloride).

6) A possible effect on extracellular polysaccharide synthesis.

The concentration of fluoride required to inhibit glucose metabolism has been found to be about 10 times higher in *Lactobacilli* than in *S. mutans* (Milnes et al., 1985). Harper and Loesche (1986) reported that the relatively low levels of fluoride found in plaque and enamel, levels attainable by water fluoridation and fluoride dentifrice use (and presumably oral rinse use), which can produce appreciable inhibition of bacterial glycolysis at the acidic pH values frequently observed in plaque. With *in vitro* tests, fluoride concentrations approximating those found in plaque were examined with respect to inhibition of lactic acid generation by resting cell suspensions of plaque bacteria in 0.1 % sucrose. In particular, the ability of the low fluoride ion concentration derived from fluorapatite was determined. The data showed that at pH 5.0, fluoride levels as low as 0.5 $\mu\text{g/ml}$ could inhibit acidogenesis by some strains of *S. mutans* by 60%, and levels of 2.3 $\mu\text{g/ml}$ or higher had an inhibitory effect on all *S. mutans* strains of bacteria tested. Fluorapatite was able to inhibit acid production, but only under conditions of low pH. The results suggested that fluoride incorporated into enamel can act as a repository for potentially

antimetabolic reserves of fluoride which, at low pH, ie., of demineralization, can be released in concentrations high enough to inhibit bacterial acid production.

It is apparent that plaque bacteria can be involved dynamically in fluoride uptake and release, and that on some occasions fluoride can directly influence bacterial plaque metabolism. It is not valid at this time to discount the importance of the bacteria-fluoride relation in the carious process; evidence is accumulating that reservoirs of fluoride can be present which, under appropriate conditions, can release fluoride in amounts high enough to inhibit bacterial metabolism (Levine, 1991).

2.3.2 Effect of Fluoride at the tooth surface

Early investigators of anticaries agents noted that treatment of intact enamel with certain compounds, including fluoride, could increase the resistance of the enamel to attack by acid.

Ten Cate and Duijsters (1983) have noted that enamel containing fluoride is less acid-soluble than enamel "without" fluoride, and, as a result, demineralization starts at a lower "critical" pH after sugar consumption. Also, fluoride enhances the rate of crystal growth, which could result in larger crystallites and more resistant enamel (as well as favoring remineralization in the tooth repair process). These investigators further observed that fluoride is present in the mouth at all times. After eruption of the teeth, the outer enamel is constantly de- and remineralized, resulting in a high fluoride content. After any type of fluoride administration, such as fluoride application, rinsing, or brushing, the oral fluid concentration decreases exponentially with a half-life of about 1 hour. Thus the free fluoride concentration in plaque can be expected to be in the 1 ppm range for extended periods during the day. Since it is known that "subcritical" pH values of 4.7-5.3 occur 2-7 hours daily, the investigators conducted experiments with enamel specimens accordingly.

These studies by Ten Cate and Duijsters involved examination of the demineralization of dental enamel in undersaturated calcium phosphate solutions with different pH and fluoride concentrations. The data showed a dissolution pattern not

significantly different from stoichiometric hydroxyapatite dissolution ($\text{Ca/P} = 1.72$). During the initial demineralization, calcium was removed preferentially. The rate of demineralization was affected to a greater extent when the solution was supersaturated to calcium fluoride rather than to fluorapatite. This was attributed to a different morphology of calcium fluoride deposition, which effectively blocks acid diffusion. During the demineralization process, fluoride was taken up by the enamel. The fluoride removed from the solution was correlated with the amount of demineralization.

Margolis et al. (1986) have taken the quantitative role of fluoride in surface demineralization to the ultimate. They found that the presence of only 0.024 or 0.054 ppm fluoride provided protection of the enamel surface as well as a favorable effect on the development of subsurface lesions. Even with a demineralizing solution containing 0.154 ppm fluoride, however, subsurface demineralization occurred. With 1ppm fluoride in the demineralization solution, no mineral loss was detected. Inhibition of enamel demineralization was also associated with an increase in solution supersaturation with respect to fluoridated apatite. These results support *in vivo* data of Pearce and co-worker (1982, 1985) who demonstrated that the deposition of sufficient amounts of fluoridated apatite can markedly inhibit intraoral demineralization of oral enamel blocks, and that those amounts of fluoride can promote the remineralization of previously demineralized enamel.

Therefore, fluoride is strongly associated with surface demineralization-remineralization phenomena.

2.3.3 Fluoride and remineralization of enamel

Featherstone (1983, p.89) reviewed studies wherein the effect of fluoride on remineralization of white-spot lesions *in vivo* was studied primarily with the aid of prosthetic devices in which enamel specimens containing induced white-spot lesions were worn by subjects. It was suggested that frequent applications of fluoride at relatively low concentrations could be more beneficial than concentrated solutions

applied intermittently. Featherstone also examined the possibility of rapid remineralization of white-spot lesions. The results demonstrated the remineralizing capacity of the oral environment. All the subjects lived in the same fluoridated water area (1 ppm fluoride). This appeared to be reflected in a measurable degree of remineralization by saliva in combination with fluoride at this low level in just 14 days.

2.4 Conclusions so far

The sum total of the evidence indicates that fluoride has multiple mechanisms of action, and that these reside in three major loci: in the plaque above the tooth surface, at the interface of the plaque and the tooth enamel, and below the tooth surface. The most important site from the clinical point of view is the plaque /enamel interface. It has been demonstrated that major protective effects from fluoride can be anticipated at very low fluoride concentrations, and that those effects can have consequences with respect to occurrences above and below the enamel surface. Furthermore, the opinion prevails that frequency of application of fluoride, or, more important, the presence of fluoride during acid challenge, is more important to the efficacy of fluoride than the concentration of the fluoride (Featherstone et al., 1990). Indeed, excessively high levels of fluoride have apparently been counterproductive in some experiments.

The concept of frequency of application being more important than concentration explains many features of fluoride protection. For example, sodium monofluorophosphate in clinical trials has been shown to be as effective in terms of caries reduction as sodium fluoride, despite a substantially lower level of fluoride ion provided by the former. Some have attributed this to the fluoride present in commercial preparations of sodium monofluorophosphate; others have demonstrated hydrolysis of monofluorophosphate by dental plaque microorganisms (Jackson, 1982). Although accumulation of sodium monofluorophosphate in plaque and

hydrolysis is an attractive hypothesis, the evidence points to the need for only minimal amounts of fluoride ion to provide protection so long as the ion is present at sites of potential demineralization. Thus, the amount of fluoride delivered by an agent or vehicle is not as important as the constancy with which fluoride is present at the enamel surface during cariogenic acid challenge. Obviously, the higher the initial fluoride concentration, the longer it will take for fluoride to be cleared from the mouth, and the greater will be the expectation for heightened anticaries efficacy with high-fluoride dentifrices and oral rinses.

2.5 Orthodontic materials providing fluoride release

Since fluoride is an accepted aid in the protection of enamel against acid attack, its availability to the enamel from different sources could be of value.

2.5.1 Fluoride-containing etchant

Several authors (Kochvi et al., 1975; Gedalia et al., 1980; Bohrer and Gedalia, 1980; Freeman and Shannon, 1981; Thornton et al., 1986) have concluded that the addition of fluoride to phosphoric acid etchant had no significant effect to enamel caries prevention or deterioration on the etching effect on enamel. However, the bond strengths of sealants to enamel surfaces etched with phosphoric acid containing fluoride were dependent on the fluoride concentrations in the etching solutions (Wright and Beck, 1973; Grajower et al., 1979; Takahashi et al., 1980).

2.5.2 Fluoride containing cements for banding

Attempt has been made to add fluoride agents (mostly SnF_2 or $\text{Na}_2\text{PO}_3\text{F}$) to the liquid or solid components of orthodontic cements; zinc phosphate (Wei and Sierk, 1971), silicophosphate (Galen, 1973), reinforced zinc oxide eugenol (Wei and Bitner, 1973) and carboxylate cements (Bitner and Wei, 1973). The polyalkenoate cements have been shown clinically to be associated with less decalcification than zinc

phosphate or zinc poly acrylate. (Maijer and Smith, 1988; Mizrahi, 1988; Durning, 1989) Whether this is due to the increased fluoride content of glass ionomer cements per se (Swartz et al., 1984), or their increased adhesion and better band retention (Norris et al., 1986), is still controversial. Some authors have demonstrated that the fluoride-containing cements have preventive effect on demineralization (Sadowsky et al., 1981; Valk and Davidson, 1987).

2.5.3 Fluoride-containing bonding adhesives

These are glass ionomer cements and composite resin. An *in vitro* study (Valk and Davidson, 1987) indicated that glass ionomer cement protected an area of approximately 1 mm wide around the orthodontic bracket. Some studies have shown that the fluoride-exchanging resin has caries-preventive effect (Rawls and Zimmerman, 1983; Sonis and Snell, 1989; Underwood, 1989). However, a study using fluoride-releasing composite resin by Fox (1990) showed that the therapeutic effect of decalcification protection due to the fluoride-release was scarcely significant. This finding is supported by Chan et al. (1990) and Bishara et al. (1991). Additionally, the bond strength is still questionable (Murray and Yates, 1984; Sonis and Snell, 1989; Chan et al., 1990; McCourt et al., 1991; Aasrum et al., 1993).

2.5.4 Fluoride varnish

The topical application of fluoride predisposes to the formation of readily soluble calcium fluoride (CaF_2) crystals on the enamel surface. *In vivo* experiments on direct bonding of plastic attachments, by Newman and Cimasoni (1971) achieved a significant fluoride uptake down to a depth of at least 60 microns when the enamel surface was pretreated with APF for 1 minute and covered for two to three months with an adhesive containing NaPO_3F . There is a finding that a fluoride varnish (Fluor Protector) is very effective in the prevention of white spot formation under molar bands (Bounoure and Vezin, 1980; Adriaens et al., 1990).

2.5.5 Fluoride-releasing plastic modules

These have been investigated in an (unpublished) *in vitro* study by Schemehom and Farnham (1988). The 10 % stannous fluoride elastomeric ties showed greater remineralization of adjacent enamel than the 1.4 % modules (Mitchell, 1992). No clinical data has yet been published.

2.5.6 Fluoride releasing elastic chain.

The recent study done by Joseph et al. (1993) suggested that the rate and the amount of stannous fluoride release from a fluoride-impregnated elastic power chain was initially high (0.106 mg/hour between 6-24 hours), but dropped dramatically after 72 hours and remained at low levels until the end of experimental period. However, as previously noted, the level of fluoride ion level depends on the pH and the concentration of salivary ions present. This study claimed that a minimum continuous level of 0.025 mg of fluoride must be available for remineralization to occur. Therefore, the reservoir of very low level of fluoride had minimal remineralization affect after one week.

Ten Cate (1990) commented that the reservoir of fluoride had probably been exhausted by this time and the remineralization effect thereafter would be minimal. However, there may be some bacteriocidal influence even at the low levels of fluoride release.

Several types of orthodontic material that release fluoride are effective in decalcification protection, even though some of them release only small concentration of fluoride ion (Chan et al., 1990). However, as noted earlier Featherstone et al. (1990) have demonstrated that simply increasing fluoride concentration may not necessarily give increased cariostatic benefit, and improving the means of delivery gives a relatively low enhancing clinical effect.

Using these fluoride-providing materials as an additional fluoride reservoir might benefit decalcification prevention which may meet the treatment

needs of the individual patient with a high caries risk or poor oral hygiene habit. Regular topical applications of fluoride may still be necessary to provide full protection especially where water fluoridation is not available.

CHAPTER 3

FORCES AND DENTAL ARCH SPACE CLOSURE

3.1 Space closure systems

An ideal force-delivering system should attempt to meet the following criteria :

- 1) provide optimal tooth-moving forces to elicit the desired effect,
- 2) be comfortable and hygienic to the patient,
- 3) require minimal operator manipulation and chair time,
- 4) require minimal patient cooperation,
- 5) be economical (Burstone, 1982; von Fraunhofer et al., 1992).

3.2 Forces in space closure

3.2.1 Optimal force

Nikolai (1975) has a definition of optimal orthodontic force based on several authors (Storey and Smith, 1952; Hixon et al., 1969; Burstone, 1962; Gianelly and Goldman, 1971) as "The optimal force produces a maximum desirable biologic response with minimum tissue damage, resulting in rapid tooth movement with little or no clinical discomfort".

3.2.2 Factors which influence optimal force (Nikolai, 1975)

1) Tooth root surface area and shape

For a constant force, the optimum range can be expected to vary with the surface area of the tooth root so that the pressure at the tooth/bone interface becomes of prime clinical importance (Storey and Smith, 1952).

2) The type of tooth movement desired

A range of forces for optimal physiological tooth movement is advocated by Gianelly and Goldman (1971) (Table 2).

Table 2 Type of tooth movement and optimal force (from Gianelly and Goldman, 1971, p.164)

1) tipping	small root	20-30 g
	large root	50-75 g
2) root torque	small root	50 g
	large root	120-150 g
3) bodily movement	small root	40-50 g
	large root	150 g
4) extrusion		25-30 g
5) intrusion		15-50 g

3) Magnitude-time pattern of the crown force system to be applied:
continuous Schwartz (1932), in an investigation of orthodontic springs, concluded that, biologically, the most favourable levels of force were those that did not produce periodontal pressures which exceed the arterial pressure of the blood capillaries (20-26 g/cm²).

Weinstein (1967) reported that a 2 g force successfully displaced a premolar and this might be understood as being a threshold value for the tipping of that tooth.

Storey (1973) has investigated force magnitude in canine retraction and found that there is little difference in total canine movement between the heavy forces (500 g) and the light force (250 g) but with heavy forces much more anchor tooth movement occurred. The anchor units moved three times as far with heavy as with light forces.

On the contrary, Hixon et al. (1969) investigated a broad range of the canine retraction forces from 64 to 1515 g. They postulated that higher forces per unit root area (to 3 or 4 g/cm²) increase the rate of biologic response. The applied force less than 300 g retracts the canine more reasonably because when the retraction force

exceeds 300 g, it becomes difficult to counteract the rotation and tipping without traction on the lingual side. This finding was supported by similar study by Boester and Johnston (1974) which demonstrated that in their system forces more than 140 g produce no increase in tooth movement.

Quinn and Yoshikawa (1985) suggest from clinical data that the best estimate of an efficient maxillary canine retraction force is between 100 and 200 g. This would yield mean compressive stresses for the average cuspid root (assuming one half of the root surface to be under compressive stresses) of approximately 70 to 140 g/cm². This range of force is used as a model to explain the two clinical strategies for achieving the maximum anchorage, being:

- 1) Increase the root surface area. Either incorporate the second molars into the anchorage unit, or by making extractions more anteriorly in the arch. By the same rationale, extraction of second premolar teeth would be a logical choice in case of minimum anchorage requirements.

- 2) Use the appliance system that can deliver relatively continuous forces in the range 100 to 200 g. Large force produces an increase in the rate of movement of posterior teeth without increasing retraction of anterior teeth.

Burstone (1982) observed that these treatment design characteristics are best achieved by means of low modulus materials and appropriate closing loop geometries.

4) Individual biology (tissue response)

Several experimental reports to date strengthen the hypothesis that there is an optimum range of force which will induce a maximum rate of tooth movement when an orthodontic appliance is first attached to a tooth. This differs in different species of experimental animals and is affected by age, sex, hormonal and dietary factors (Storey, 1973).

Some factors determining the evaluation of forces in orthodontics are:

- 1) the individual variation in tissue reaction,

- 2) the type of force applied, either continuous-interrupted or continuous-intermittent forces,
- 3) the mechanical principles involved: tipping, or bodily movement (Reitan, 1957).

Table 3 Selected clinical studies measuring the effect of force magnitude on orthodontic tooth movement (Quinn et al., 1985, p.255)

Author	Patients (no.)	Observation (weeks)	Measurement technique	Mechanics	Force levels	Results
Smith and Storey ²	8	4 to 10	Observation—weekly Measurement—calipers, intraoral Reference—opposite arch	See Fig. 3.	185 gm vs. 238 gm ⁴	Cuspid displacement greater than the molar at both force levels. ^{a,c} Heavy forces yielded greater molar displacement than light forces. ^{a,c}
Andreasen and Zwanziger ³	14	10	Observation—weekly Measurement—calipers, intraoral Reference—incisors	See Fig. 4.	100 to 150 gm vs. 400 to 500 gm	Heavier forces showed greater molar displacement. ^{a,b}
Hixon et al. ³	8	8	Observation—biweekly Measurement—calipers, models Reference—25° cephalograms, endosseous implants	See Fig. 5.	300 gm vs. 0 to 1,500 gm	Higher forces produce greater tooth displacement up to 300 gm.
Hixon et al. ⁶	6	8	Observation—3 times per week Measurement—calipers, models Reference—25° cephalograms, endosseous implants	See Fig. 6.	300 gm vs. 0 to 1,000 gm	Higher forces yielded greater tooth displacement.
Boester and Johnston ⁴	10	10	Observation—weekly Measurement—calipers intraoral, models Reference—22.5° cephalogram, structural references	See Fig. 7.	55 gm, 140 gm, 225 gm, 310 gm	55-gm force yielded less tooth movement than higher forces. ^d Above 140 gm no increase in tooth displacement was observed.
Andreasen and Johnson ⁷	16	12	Observation—weekly Measurement—calipers, intraoral Reference—incisors	See Fig. 8.	200 gm vs. 400 gm	Higher force levels yielded 2.5 × the tooth displacement of the lower force. ^c

^aReviewers' interpretation of original data.
^bP < 0.05 paired t test (2 tail).
^cP < 0.01 paired t test (2 tail).
^dP < 0.05 ANOVA.

3.2.3 Rate of tooth movement

The data of Weinstein and associates (1963) on equilibrium tooth position shows that force as small as 4 gm can move teeth at a measurable rate-approximately 0.1 mm/week.

Within the optimum range, tooth movement is rapid, but the quality of remodelling bone is poor. It will continue to remodel rapidly toward a more mature state even after treatment, so that the potential for relapse is high. In the low range of forces, tooth movement is slower but steadier and, proceeding by a repeated undermining process, so the quality of new bone is better and the potential for relapse less. The rate of movement of the order of 0.5 mm per week should provide adequate scope for reasonably short periods of clinical treatment. This has been demonstrated by the successful development of a light force removable appliance system delivering loads of the order of 75 to 100 g (Storey, 1954).

Several studies have been agreed that the rate of tooth movement may be estimated to be around 1 mm per four-week period (Hixon et al., 1969; Paulson et al., 1970; Huffmann and Way, 1983).

3.3 Intra-oral methods of space closure

Intra-oral mechanics for closing the space in the dental arch may be achieved by\ (Burstone, 1982):

1) Sliding mechanics. The movement depends on the axial inclination of the canine relative to the occlusal plane, the width and slot size of the brackets and the thickness of the archwire used, and is achieved with:

- a) Elastic thread
- b) A-elastic chain module
- c) Intra- or intermaxillary elastics to Kobayashi ligatures or bracket hook.

There is no significant differences in rates of canine retraction by using elastic thread and elastomeric auxiliaries. The elastomeric auxiliaries were found to be

more hygienic and required less chair time to apply than did the elastic thread (Sonis et al., 1986).

d) Coil springs

e) Sliding jig and traction

2) Distal movement with the archwire by sectional archwire (Burstone, 1982).

3) Archwire closing loops.

CHAPTER 4

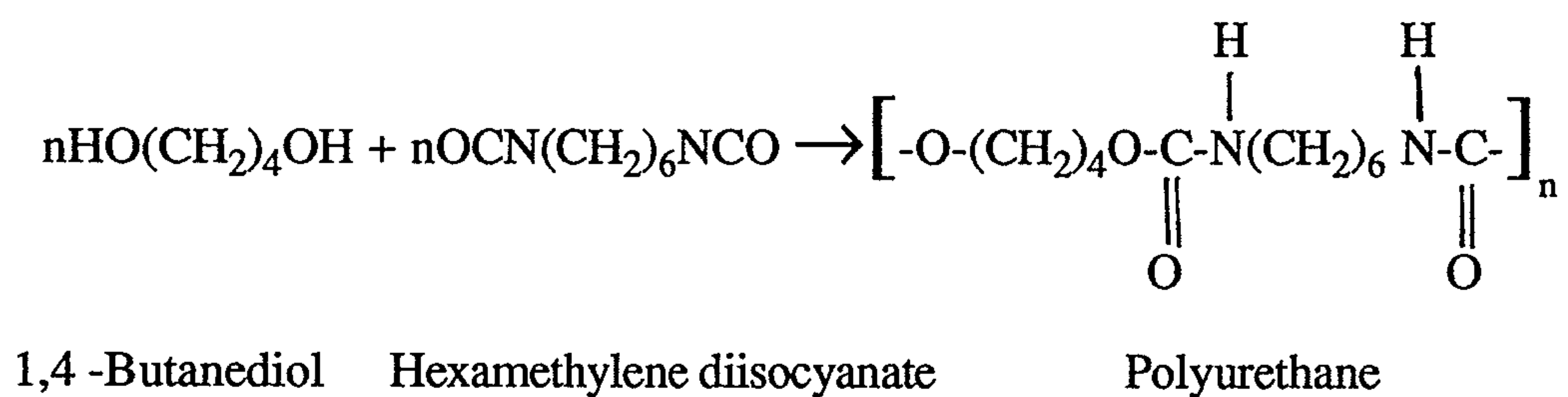
NATURE OF ELASTOMERIC POLYURETHANE MATERIAL

Elastomerics are polymers which are viscoelastic materials, having the properties of solids and viscous liquids. These properties are time- and temperature dependent. Thus the effects of the rate of application of stress and the ambient temperature must be recognized when polymers are used as structural materials, and definite rates of strain and temperatures must be specified for tests. A knowledge of the structure of polymers is essential for the understanding of these effects.

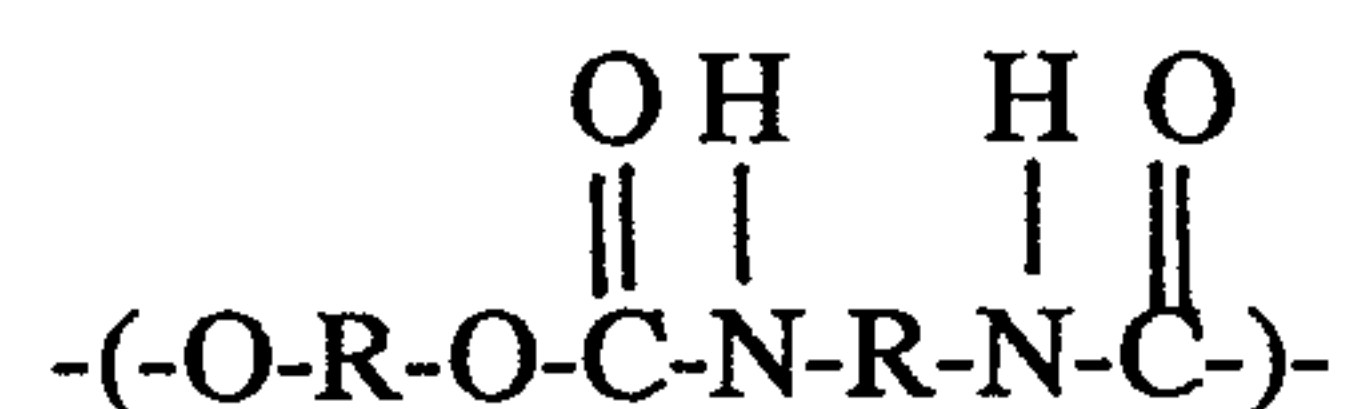
Polyurethane rubber is a generic term for the elastic polymers which contain the urethane linkage.

4.1 Chemical structure

Polyurethanes are synthesized by the reaction of a diisocyanate and a diol or higher polyol. The exact composition is proprietary information. A typical PU is synthesized using the reactants 1,4-butanediol and hexamethylene diisocyanate as shown (Seymour and Carraher, 1984, p.14):

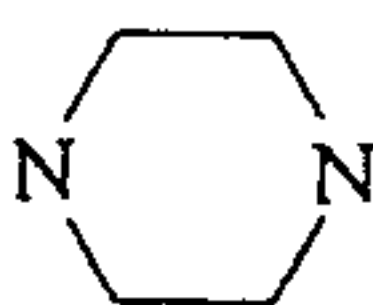
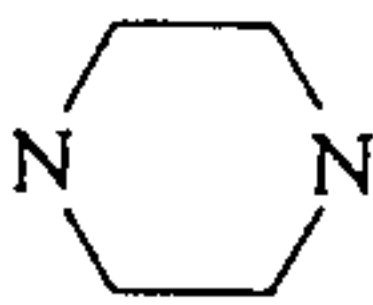


PUs have the following repeating unit (Seymour and Carraher, 1984, p.171):



The properties of these versatile polymers may be modified by changes in composition. The polymer produced by the reaction of a diisocyanate with four carbon atoms and a glycol with four carbon atoms has a higher melting point T_m (190° celsius) than one produced from a diisocyanate with five carbon atoms and a glycol with four carbon atoms (159° celsius). The T_m and the water absorption decrease, and the flexibility increases, as the number of carbon atoms between characteristic groups is increased.

The T_m's of PUs are lower than those of corresponding nylons, but they have greater affinity for dyes and have lower water absorption. PUs are usually soluble in formic acid and phenol. The T_m values of selected PUs are shown in Table 4

$\left(\text{O} - \left(\text{CH}_2 \right)_m - \text{O} - \overset{\text{O}}{\parallel} \text{C} - \overset{\text{(H)}}{\mid} \text{N} - \text{R} - \overset{\text{(H)}}{\mid} \text{N} - \overset{\text{O}}{\parallel} \text{C} \right)$		
<i>m</i>	R (or diamine fraction)	Melting Point (°C)
2	1,2-Ethylene	225
2	1,4-Hexamethylene	180
6	1,6-Hexamethylene	170
2		250
6		120

m = methylene units

Table 4 Crystalline melting points for selected polyurethanes (Seymour and Carraher, 1984, p.173).

PUs are resistant to aqueous alkalines, salts and acids. Because of the availability of hydrogen bonds, PUs bond well to other "polar-like" surfaces, including glass.

The Tm generally increases as the flexible units are replaced by nonflexible units, as phenylenes and piperazines. Thermal and physical properties of aliphatic PUs are shown in Table 5.

Table 5 Aliphatic polyurethanes (PUs) (Seymour and Carraher, 1984, p.174)

Thermal and physical properties of plastics (typical values)	Cast PU	Elastomer PU
Maximum resistance to continuous heat (°C)	70	65
Coefficient of linear expansion cm/cm · °C × 10 ⁻⁵	15.0	15.0
Compressive strength (kPa)	138,000	138,000
Flexural strength (kPa)	20,680	27,500
Impact strength (Izod: cm · N/cm of notch)	1335.0	No break
Tensile strength (kPa)	6,890	7,250
Elongation (%)	200	150
Specific gravity	1.2	1.15

4.2 Physical characteristic of elastomers (Seymour and Carraher, 1984, p.20, 29)

Elastomers are high-molecular-weight polymers possessing chemical and/or physical cross-linking. For industrial application, the temperature at which the elastomer is used must be above the Tg¹ (to allow for full "chain" mobility), and in its normal state (unextended), the elastomer must be amorphous. The restoring force, after elongation, is largely entropic. As the material is elongated, the random chains are forced to occupy more-ordered positions. On release of the applied force, the chains tend to return to a more-random state.

Elastomers can undergo large elongation under load at room temperature and return to their original shape when the load is released (Nielson, 1985, p.27).

¹ Tg =The glass transition temperature, Tg is the temperature at which this segmental or micro-Brownian motion of amorphous polymers becomes significant as the temperature increases. Because of the kinetic energy present in the molecule, amorphous flexible polymer chains are usually in constant motion at ordinary temperatures.

Gross mobility of entire chains must be low. The cohesive energy forces between chains of elastomer permit rapid, easy expansion. In its extended extension it has a low modulus. Polymers with low cross-link density usually meet the desired property requirements. The material after deformation returns to its original shape because of the cross-linking. This property is often referred to as "elastic memory".

PU's have strong polar molecules, which are attracted to each other by a special type of dipole-dipole interaction called "hydrogen bonding" in which the oxygen atoms in one molecule are attracted to the hydrogen atoms in another molecule. These are the strongest of the intermolecular hydrogen bonds.

In general, the absorption of small molecules such as water acts to decrease the intermolecular forces between chains. Absorption is an attraction property in which likes attract. The polar polymers such as PU and nylon readily absorb water, the effect being to disrupt hydrogen bonding between chains. In general, properties requiring strong interchain bonding between tensile strength, flexural modulus and yield strength, are decreased as water is added, whereas properties assisted by chain flexibility and "slickness" such as elongation at break and elongation at yield are increased (Seymour and Carraher, 1984, p.65).

CHAPTER 5

MECHANICAL PROPERTY TESTS OF POLYMERS

There are a variety of methods which are useful in predicting mechanical performance properties. The more commonly employed techniques according to Nielsen (1974, p.4-18) are:

5.1 Creep tests

In creep tests one measures over a period of time the deformation brought about by a constant load or force. Most creep tests measure the change in length of a specimen by a constant tensile force, but creep tests in shear, torsion, or compression also are made. If the material is very stiff and brittle, creep tests often are made in flexure, but in such cases the stress is not constant throughout the thickness of the specimen even though the applied load is constant. In a creep test the deformation increases with time.

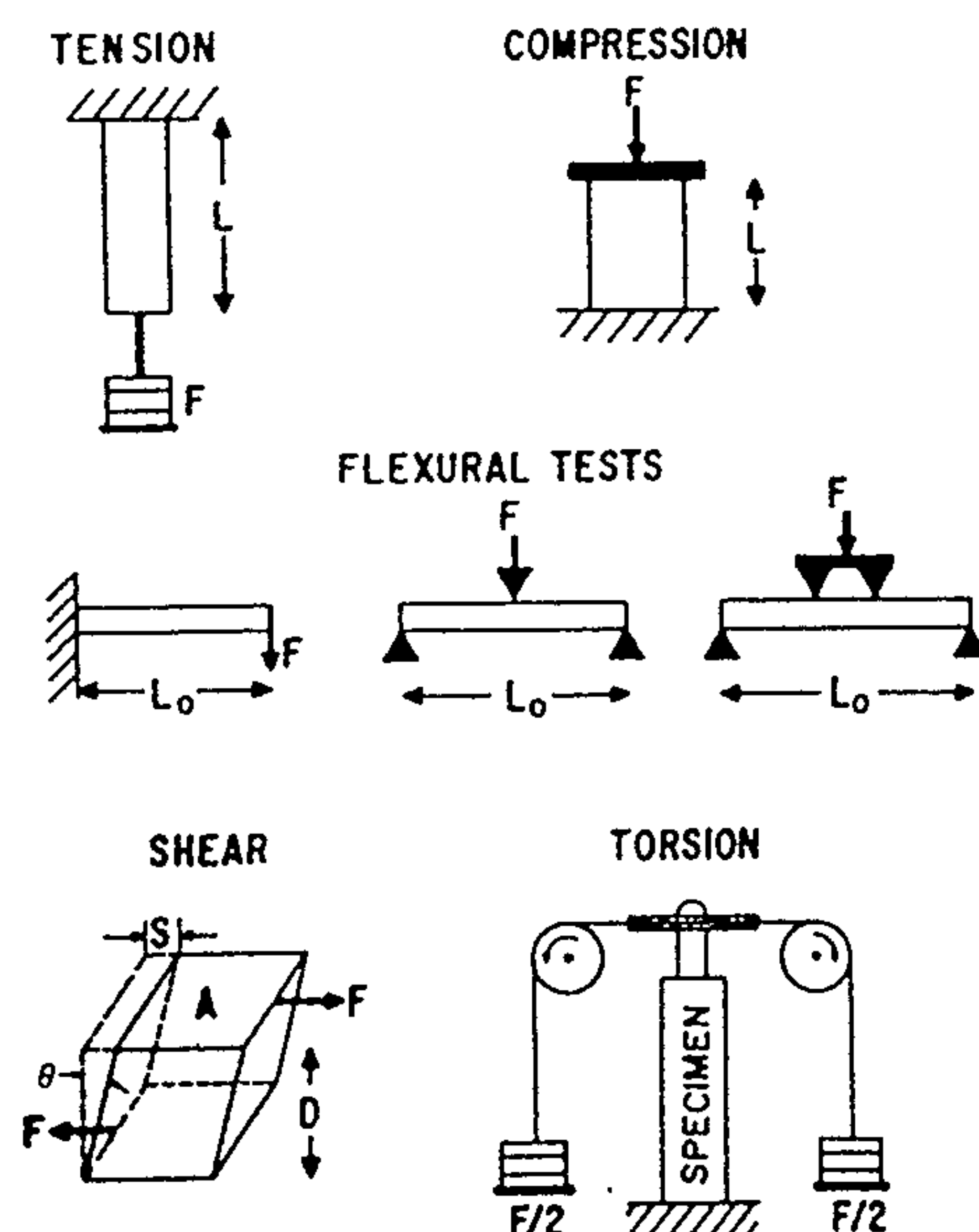


Fig. 1 Types of creep tests (Nielsen, 1974, p. 7)

If the load is removed from a creep specimen , there is a tendency after some time for the specimen to return to its original length or shape. A recovery curve is thus obtained if the deformation is plotted as a function of time after the removal of the load.

5.2 Stress relaxation tests

In stress-relaxation tests, the specimen is quickly deformed to a given amount, and the stress required to hold the deformation constant is measured as a function of time. If the stress is divided by the constant strain, a modulus which decreases with time is obtained. Stress relaxation experiments are very important for the theoretical understanding of viscoelastic materials.

5.3 Stress-strain tests

In stress-strain tests the buildup of force (or stress) is measured as the specimen is being deformed at a constant rate. Occasionally stress-strain tests are modified to measure the deformation of a specimen as the force is applied at a constant rate.

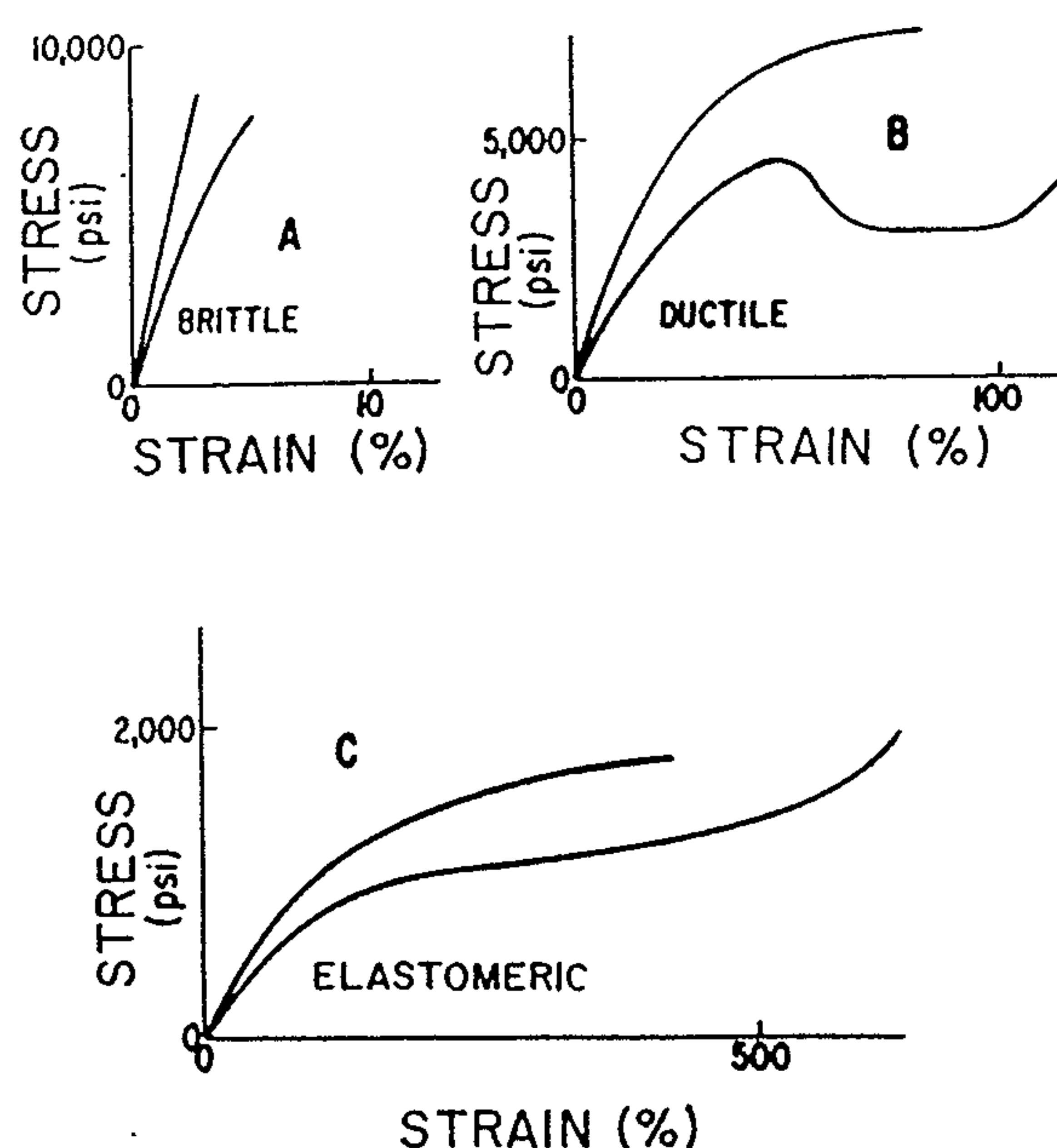


Fig. 2 General kinds of stress-strain curves (Nielsen, 1974, p. 8)

Schematic diagrams above (Fig. 2) illustrate the great variation in stress-strain behaviour of polymers as measured at a constant rate of strain. The scales on these graphs are not exact but are intended to give an order-of-magnitude indication of the values encountered.

Graph A : is for hard brittle materials.

Graph B : is typical of a material which cold-draws with necking down of the cross section in a limited area of the specimen.

Graph C : are typical of elastomeric materials.

5.4 Dynamic mechanical tests

Dynamic mechanical tests measure the response of a material to a sinusoidal or other periodic stress. The general types of dynamic mechanical instruments are free vibrations, resonance force vibration, non-resonance forced vibrations, and wave or pulse propagation instruments.

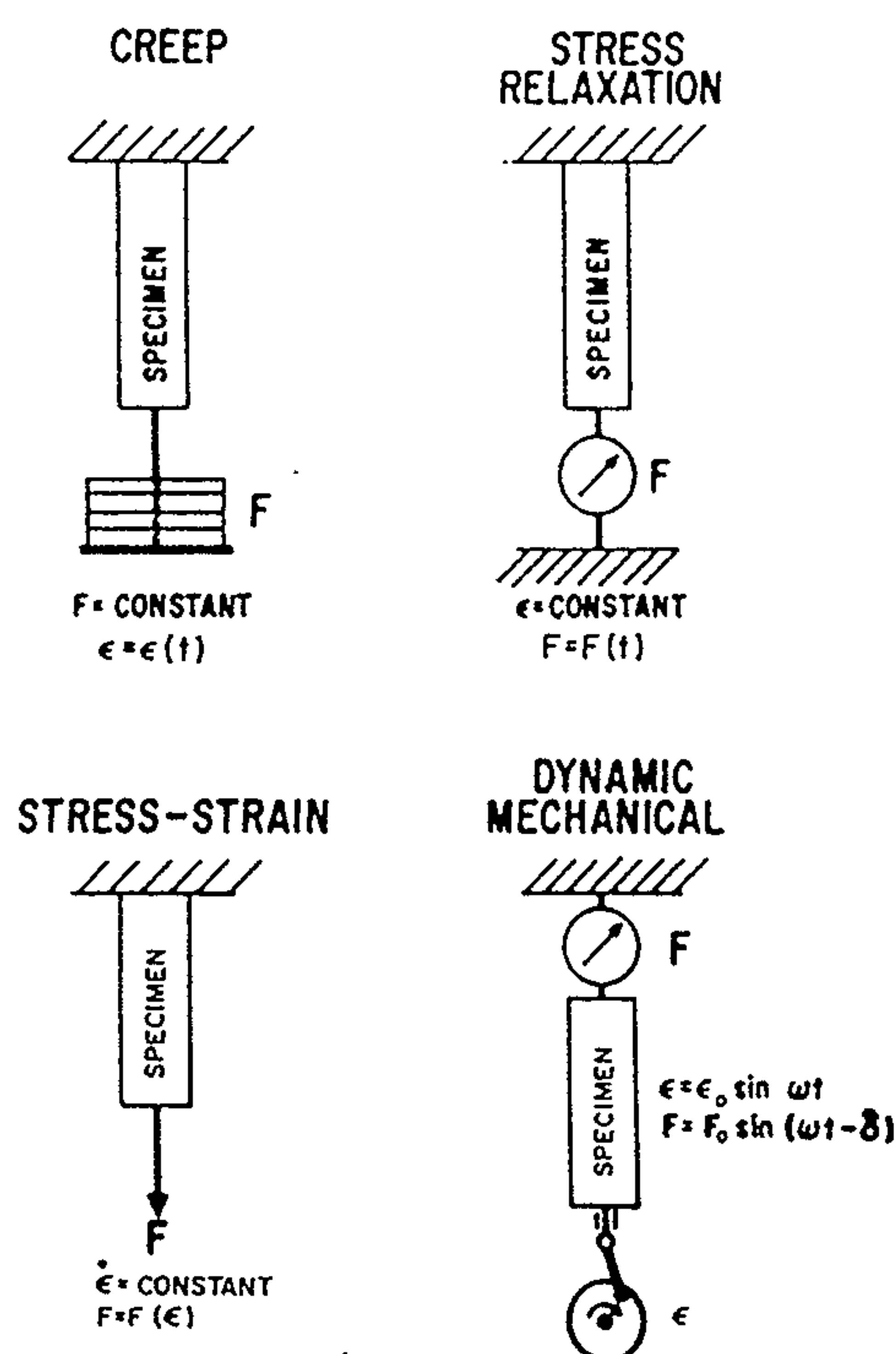


Fig. 3 Schematic diagram of various kinds of tensile tests (Nielsen, 1974, p. 6) F = force, e = strain or elongation

CHAPTER 6

ORTHODONTIC ELASTOMERIC PROPERTY STUDIES

The plastic elastic known as Alastik (Unitek) was first introduced to orthodontists in 1969 and the earliest elastic studies were done by Bishara and Andreasen (1970). They studied the rate of force decay of elastics using intermaxillary mechanics (rubber elastic or plastic Alastik). In their study, forces between 70-400 g were used in varied lengths stretching from 22 to 40 mm, increasing by 6 mm in each segment (22, 28, 34, 40). Before testing the decay of force, samples of rubber elastics were submerged in water at 37° C for 1 minute, 1 hour, 24 hours, 1 week, 2 weeks, and 3 weeks. They found that (a) the over-all behaviour of rubber elastics and plastic Alastiks showed certain similarities, but one will also find differences which have clinical significance; (b) rubber elastics maintain a relatively constant force when compared with plastic Alastiks; (c) rubber elastics have fewer variations in their forces than plastic Alastiks; (d) there is more deformation in shape in plastic Alastiks than rubber elastic; (e) oral conditions affect both the appearance and the properties of both elastic and Alastiks; (f) the clinician has more control but there is less reliability with the force applied in plastic Alastiks; (g) in absolute and relative values heavy plastic Alastiks lose more force than standard ones.

In a second study Andreasen and Bishara (1970) tested the range of stress- relaxation force of latex elastics used in space closure. They demonstrated that elastic behaviour and force range is affected by time intervals and concluded that there is an initial decay, and most of this drop occurs during the first day; elastic 41% and Alastik 74%. Therefore, they suggested to choose Alastik modules that have initial forces about four times greater than those forces the orthodontist wishes to have on the tooth after the first day and since elastics lose about 40% of their initial force after one day, one should choose an elastic with an initial force of 40% more.

In 1970, Ware and Evers-Buckland (Part 1) summarised the general properties of elastics bands and load/extension and the range and properties of elastics in use in Australia from returned questionnaires. They also tested the elastics to determine the quality of the material by preparation and application of a standard.

Ware (1971) reported on the physical properties of the plastics modules in comparison with latex elastics: load-extension ratio, the effect of temperature and/or moisture absorption on the elastic properties, and the plastic flow of the material under strain.

Hershey and Reynolds (1975) demonstrated the force behaviour to decreased stretch dimension. The testing framework was closed at rates of 0.25 and 0.50 mm per week (simulated tooth movement) submerged in 37° C distilled water. They found that all plastic modules lost considerable force (approximately 50%) within 24 hours. The modules retained an average of 40% of their initial force after 4 weeks at zero rate of closure and almost exactly the same after 6 weeks. The modules with the decreased framework at rate 0.25 mm per week retained approximately one third the initial force after 1 month. With the rate 0.50 mm per week, the remaining force was approximately one fourth the initial force. Decay characteristics were not related to magnitude of initial forces of 284 and 573 g.

Bales et al. (1976) found that there was no statistical difference between experiments performed in the simulated oral environment and in the room temperature tests. However, contrary to the follow-up study by Ash and Nikolai (1978), they reported that bench-test experimentation of orthodontic polyurethane-based elastics in dry air and water bath environments had different results from those *in vivo* after one week following initial activation. In this experiment, the tests were made under the two conditions of dry air at room temperature (24° C average) and a warm water bath at 37° C. The results of this experiment gave the comparison of force behaviour of conventional and fluoride-releasing polyurethane under limited

variable factors. It is clear that there are several factors in the oral environment that may affect the properties of the polyurethane; mastication, oral hygiene condition, the chemistry of salivary enzymes and possibly the temperature variations associated with the ingestion of hot and cold foods.

Brooks and Hershey (1976) investigated plastic modules which were subjected to the heating process (simulated to hot beverage), the force retained reduced compared to control group, while the stretched plastic subjected to heat retained greater force. They suggested that prestretching the module can partially reduce the undesirable force.

Kovatch et al. (1976) experimented with the load-extension-time behaviour of Alastiks and found that the load-extension curves of Alastiks were sensitive to both the degree and rate of extension. When halting at a constant extension, the load decay was also dependent on the initial deformation rate. The results suggested that, clinically, these modules should be stretched slowly to position.

Wong (1976) investigated latex elastics and synthetic elastomers properties with fracture test, force decay of synthetic elastomer(stress relaxation), and the modulus of elasticity under different test conditions. He found that both latex elastics and synthetic elastomers have certain similarities and differences. In fracture tests the latex elastics showed a greater amount of loss in strength than plastic elastomers. The force decay under constant force application to latex, elastic, polymer chains, and tied loops showed that the greatest amount of force decay occurred during the first three hours in the water bath. He also suggested elastic prestretching before being placed in the mouth.

Brantley et al. (1979) have suggested a technique for the orthodontist to obtain plastic modules with nearly constant forces (within 5%) during clinical use by immersing the prestretched plastic module in distilled water at 37° C for 3 weeks before use.

Howard and Nikolai (1979) investigated the relaxation of elastic threads and the polymeric chain *in vitro* and *in vivo*. They found that force loss over time for the threads is substantially less than with the polymeric modules or chain. The accumulated force losses are significantly greater *in vivo* than in laboratory studies.

Young and Sandrik (1979) reported that prestretching to a certain length (depending on individual manufactured type) would decrease the rapid force loss of the elastic polymers. It appeared that at a high initial force level the material may have plastic deformation if the initial load exceeds the elastic limit. They felt that increasing the initial load (3-4 times) to compensate for subsequent force decay which was suggested by Andreasen and Bishara (1970) may cause periodontal capillary damage resulting in undermining resorption.

Persson et al. (1983) investigated the elastic properties of orthodontic elastic threads and noted that most threads were notably softer after storage in a wet environment. They also found that in stress-relaxation tests, stretching to one and a half times the original length 5000 times in a wet environment had a marked effect on the elastic behaviour of most threads. The force decayed up to 65% of the initial value within three weeks. After initial decay within the first day, the force generally remained constant.

Rock et al. (1985) studied the dimensions and force-extension characteristics of 13 commercially available orthodontic chain elastomeric materials. They found the relationship between force and extension had two definite transition

points in the plotted curves. Over the first linear part of the curve, the two-loop specimens had stiffness values from 0.9 to 1.6 N/mm. Stiffness fell as the number of loops increased so that four-loop chains produced 0.6-1.1 N/mm. 100 % extension produced forces in the 4-5 N range for most specimens. They also suggested that an extension of between 50% and 70% would provide the most satisfactory orthodontic force.

De Genova et al. (1985) compared force degradation of three elastomeric products under constant temperature and cycled thermal change. They found that over a 21 day-period the thermal-cycled elastomerics at 15° and 45° C (simulated oral environment) experienced less force decay. Overall, modules producing higher initial force underwent less force decay than did modules producing lower initial force values. All material were set to exert 216 to 459 g of force initially. After 21 days of simulated tooth movement, the force exerted by the elastic modules was 70 to 230 g.

Killiany and Duplessis (1985) reported the clinical observation under laboratory conditions of some new synthetic elastomeric chain. "Energy" chain (Rocky Mountain Orthodontics) retained a greater force after eight weeks than "Plastic" chain (American Orthodontics).

Rock et al. (1986) reported the effect of ageing activated orthodontic elastomeric chains for 4 weeks *in vivo*, finding that all materials decreased in force and stiffness about 50% of the original value and after 4-week period, the space closed up in the range 0-5 mm. They did not mention type of tooth movement, which presumably, was tipping movement.

Kuster et al. (1986) compared the force degradation of two brands of elastics under laboratory and intra-oral conditions. The two brands of elastics behaved

similarly. There was a more rapid and more extensive force loss during intra-oral use than in the laboratory test.

Huget et al. (1990) investigated the elasticity change of synthetic orthodontic elastomer from water storage. They concluded that exposure of the elastomer to water is a time-dependent matrix decomposition. The exposure of the elastomer to water leads first to weakening of noncovalent forces and subsequently to degradation.

Ferriter et al. (1990) have shown that the oral pH has a significant influence on the decay rate of orthodontic polyurethane chain elastics. All of the seven test products had a greater force-decay rate in the basic solution (pH 7.26) than in the acidic solution (pH 4.95) over four weeks.

The effect of artificial saliva and topical fluoride treatments on the force relaxation and change in elastomeric chain was tested by Von Fraunhofer et al. (1992). They concluded that there was less load relaxation found in chains that were immersed in distilled water and acidulated phosphate fluoride than in chains exposed only to air.

PART II PRESENT STUDY

1 Objectives

This study was to investigate whether or not the fluoride mineral in elastomerics affects the elastic properties under conditions of moisture, and temperature, to simulate the oral environment, and under dry conditions. Specifically:

1) To compare force degradation characteristic of conventional elastomeric chain and a fluoride-releasing chain in wet and dry conditions.

2) To test for variability in relationships between force magnitude, distance of stretch, and time, in fluoride-releasing elastomeric chain in wet and dry conditions.

2 Material

Conventional, non-fluoride (NF) and fluoride-releasing (F) elastomeric chain from the same manufacturer were to be tested. Both samples had the most recent manufactured date. The elastomeric chains tested in this study were matched in color and size for both the distance between chain links and the size of the links. ("A"-Company Force-A chain elastic (NF), narrow, gray, chain elastic and Fluoride-release chain elastic (F) (Fig.4). Prior to the experiment, both of the chain samples were kept in the air tight plastic bags as originally received from the manufacturer. The chain was carefully removed from the spool without stretching and was trimmed to a 4-unit length by surgical blade (No. 11) at the connection of the links. The chains were always handled by polyvinyl gloves.

Two identical brass-stainless steel test frameworks were used carrying 50 rigid metal rods (Fig. 5). These rods were free to move vertically and were adjusted for the distances 16 and 21 mm to a vertically set bar hook by unscrewing the locking screw to slide the rods vertically. One framework was submerged in 37° C distilled water controlled by a continuously circulating electric stirrer with temperature

controller (Thermomix). The other framework was used under room temperature dry air environment (23° C).

A load cell strain gauge was attached to the pin support bar which acts as guidance for the gauge to slide along in order to measure tension in each chain in turn (Fig. 7). The forces were read by multimeter in milivolt, transformed into grams (gs) by calibration with standard known weights.

3 Method and Procedure

Two sets of 40 samples of 4 unit-lengths of grey type F and NF chain were slowly loaded on extension hooks 16 and 21 mm respectively apart in each framework (for the dry and wet tests) without overstretching beyond the test lengths, according to the recommendation of Kovatch et al. (1976). Each set of the 40 samples was divided into 4-subsamples of chain consisting of 10 specimens.

Force readings were obtained at initial activation (time zero) and thereafter at 1 hour, 6 hours, 24 hours, 7 days, 28 days, 42 days. Throughout the 6-week period each rod was unscrewed from the upper bar to connect to strain gauge for the few moments to take multimeter readings. The second set of samples was kept submerged in water were taken from the water baths only for force measurements at the prescribed time points and quickly returned.

The load cell gauge was mounted perpendicular to the bar of the cross-head during the measurements and connected to a digital meter. The voltage readings were interpreted in gram-force by calibrating with the known standard weights (Appendix 2). Before each data collection, the strain gauge was calibrated by the same weights to confirm the validity of reading. The first reading was taken promptly at the moment that the multimeter figure stopped blinking.

Statistics analysis and design.

The data was analysed using three factor analysis of variance (ANOVA). The design of the experiment was three factor factorials: factors F/NF, D/W, and 16/21 which gave $2 \times 2 \times 2 = 8$ comparisons, and split plot in time (1 hr, 6 hrs, 24 hrs, 7 days, 28 days, and 42 days) with the experiment being repeated once. The level of statistical significance chosen was $P < 0.05$.

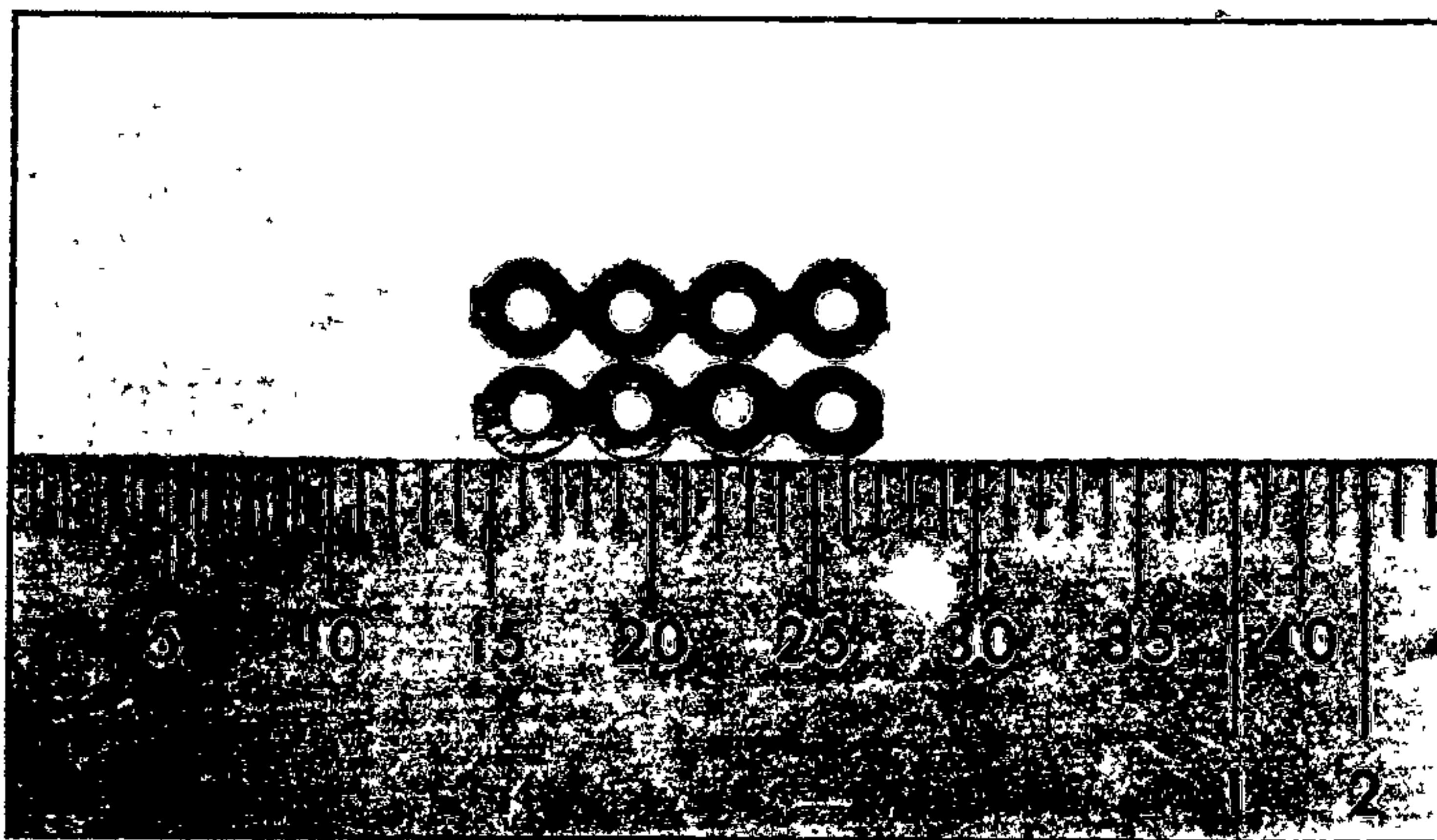


Fig. 4 Fluoride-releasing (top) and conventional (below) elastomeric chain

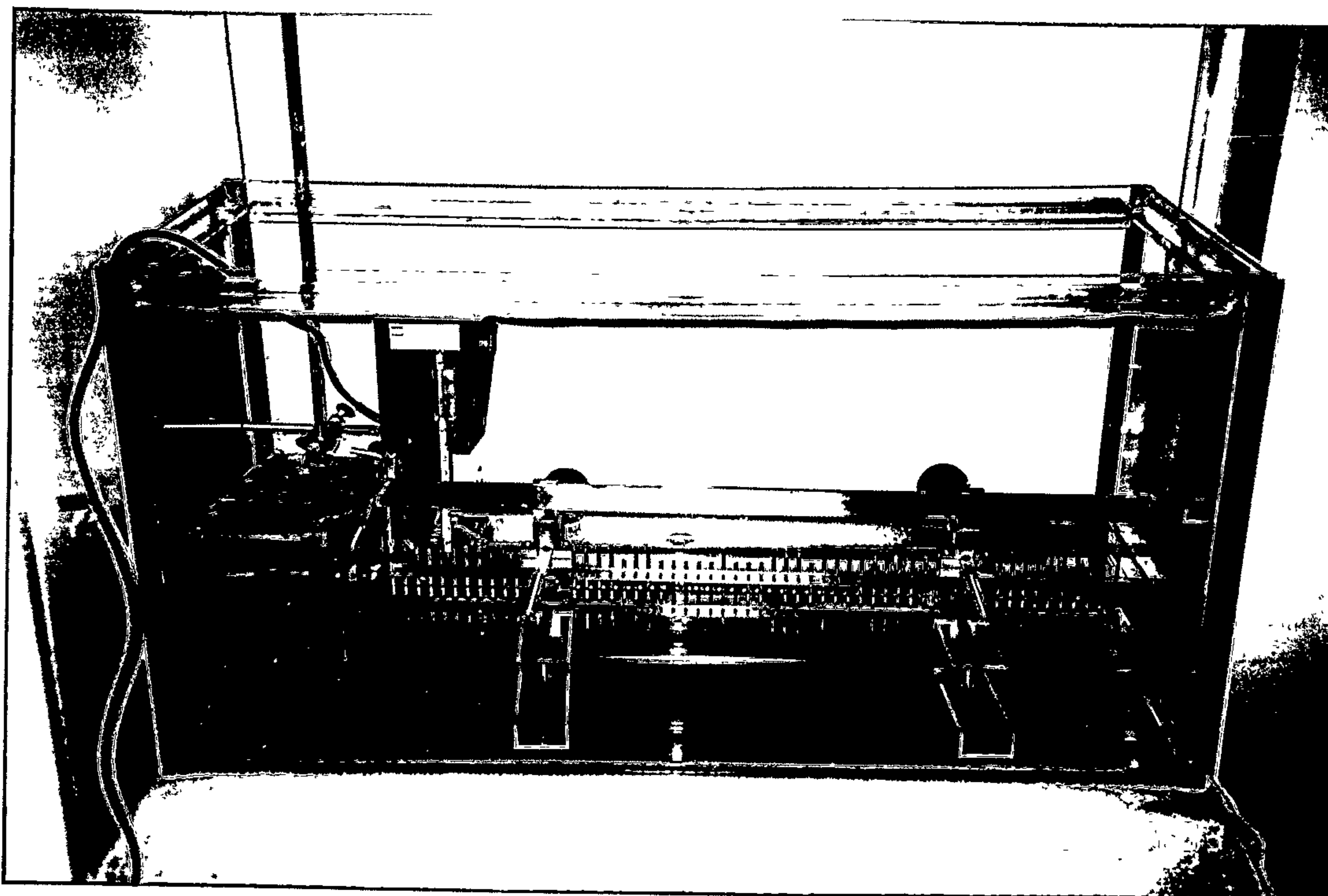


Fig. 5 Elastomeric chain test framework

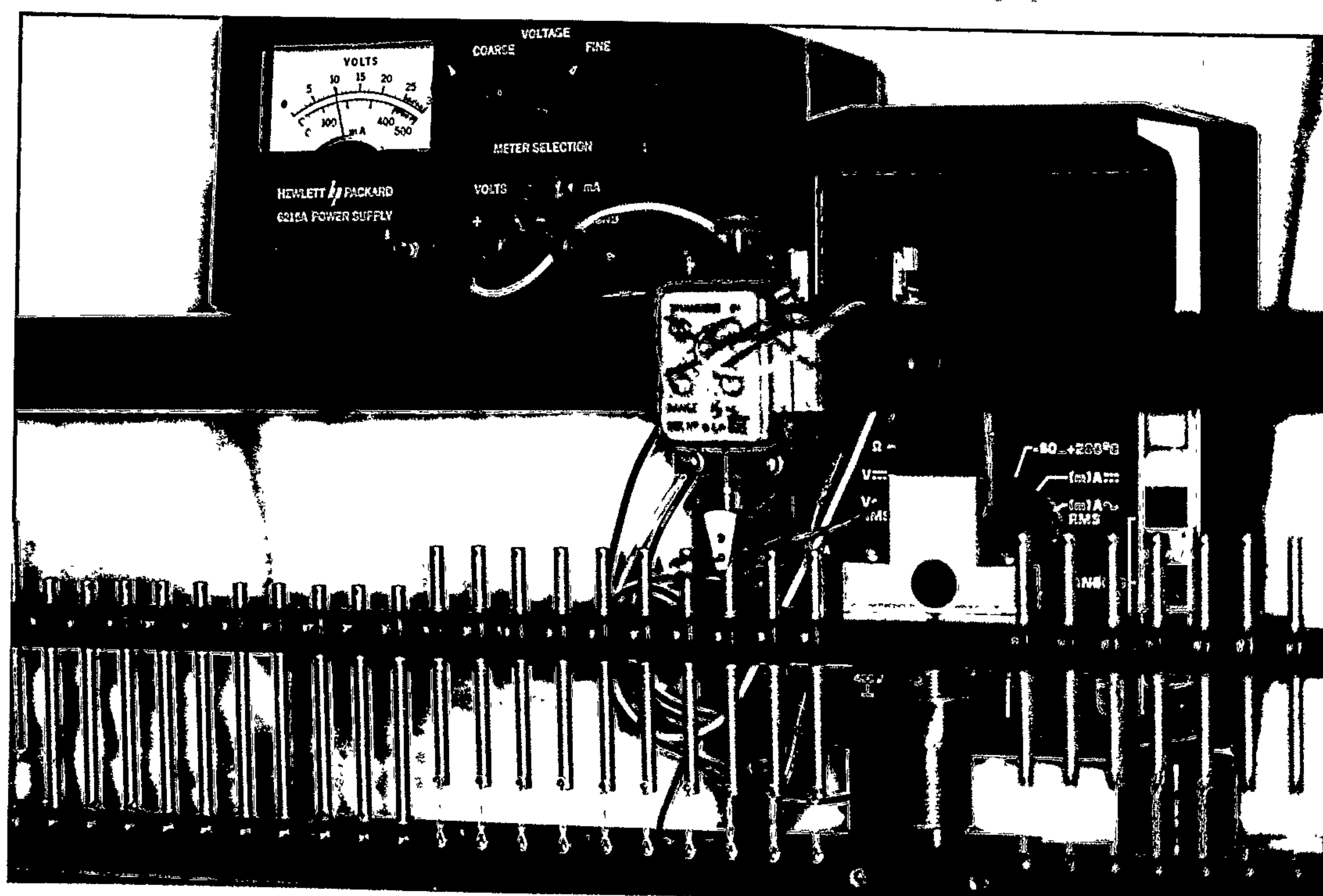


Fig. 6 Strain gauge, power supply, and multimeter

4 Results

The whole experiment was repeated using new samples. The force degradations for F and NF in air and in the water over the 42-day period were summarized in Table 6. (Table 6 records the mean force values for both sets of tests from data in Appendix 3)

The development over time of the force values of the F and NF was very similar during the the experiment. There was a progressive decrease in the force under both dry and wet conditions throughout the entire experimental period as Fig. 7 shows.

F16D = Fluoride-releasing elastomeric chain extended 16 mm in dry environment

NF16D = Conventional elastomeric chain extended 16 mm in dry environment

F21D = Fluoride-releasing elastomeric chain extended 21 mm in dry environment

NF21D = Conventional elastomeric chain extended 21 mm in dry environment

F16W = Fluoride-releasing elastomeric chain extended 16 mm in wet environment

NF16W = Conventional elastomeric chain extended 16 mm in wet environment

F21W = Fluoride-releasing elastomeric chain extended 21 mm in wet environment

NF21W = Conventional elastomeric chain extended 21 mm in wet environment

Table 6 Force degradation (means in gram-force)

	0 hour	1 hour	6 hours	24 hours	7 days	28 days	42 days
F16D	267.04	221.05	202.56	190.51	179.14	161.13	151.33
NF16D	307.7	248.26	236.61	225.25	207.07	191.39	172.05
F21D	328.61	265.26	248.74	235.08	211.34	192.44	181.16
NF21D	375.48	302.18	286.46	269.21	248.58	233.79	221.62
F16W	264.82	155.93	136.75	114.34	60.74	28.5	23.9
NF16W	290.77	185.79	174.87	158.83	148.51	127.8	116.76
F21W	320.26	182.93	163.71	141.53	94.21	58.35	49.7
NF21W	358.6	236.53	216.42	204.29	190.02	162.82	154.96

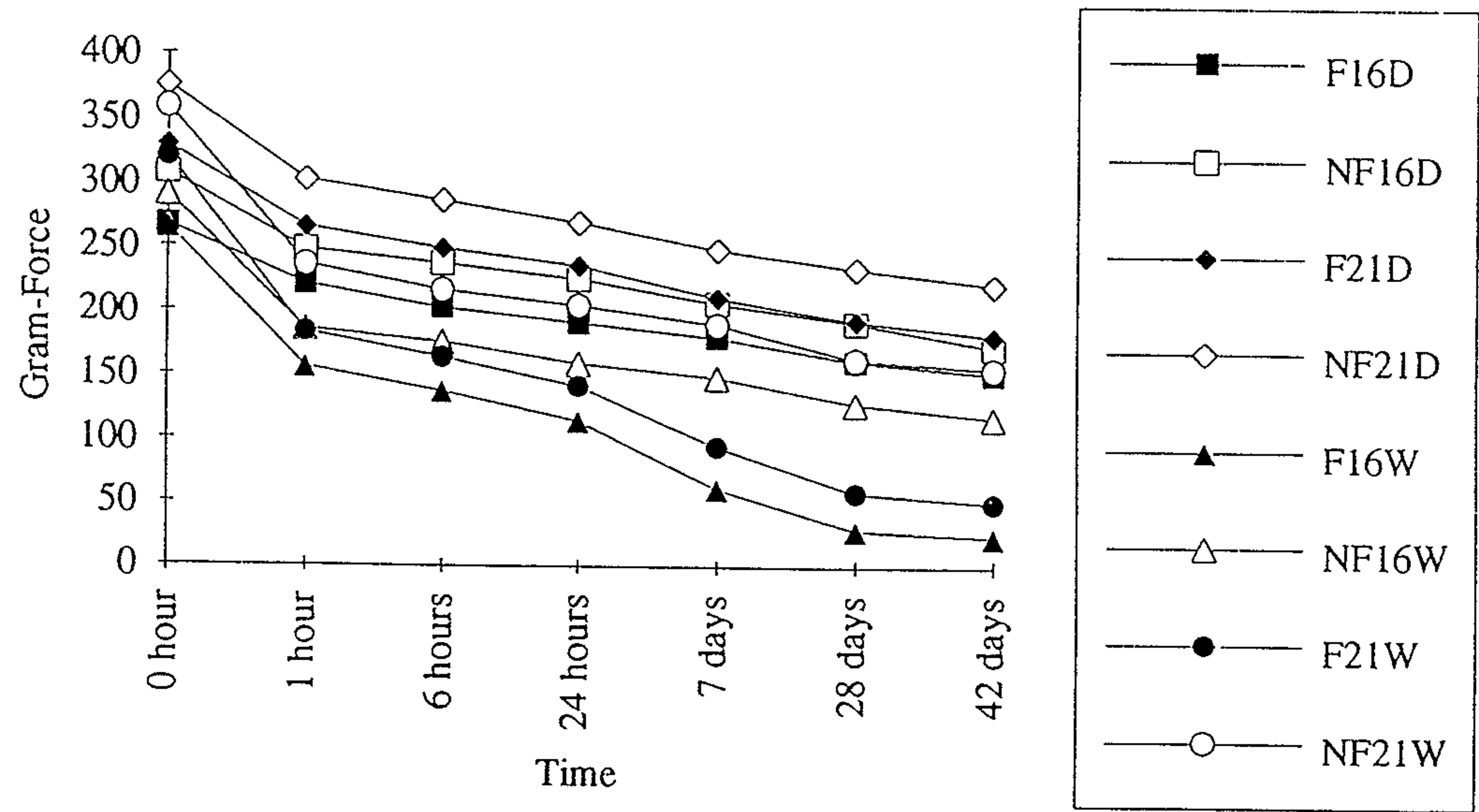


Fig. 7 Graph plots of mean force versus time for the chain subsamples

The overall percentages of force value degradation are shown in Table 7 and graphed Fig. 8

Table 7 Force degradation in mean percentage (from table 6)

	0 hour	1 hour	6 hours	24 hours	7 days	28 days	42 days
F16D	100	82.78	75.85	71.34	67.08	60.34	56.67
NF16D	100	80.68	76.90	73.20	67.30	62.20	55.91
F21D	100	80.72	75.69	71.54	64.31	58.56	55.13
NF21D	100	80.48	76.29	71.70	66.20	62.26	59.02
F16W	100	58.88	51.64	43.18	22.94	10.76	9.02
NF16W	100	63.90	60.14	54.62	51.07	43.95	40.16
F21W	100	57.12	51.12	44.19	29.42	18.22	15.52
NF21W	100	65.96	60.35	56.97	52.99	45.40	43.21

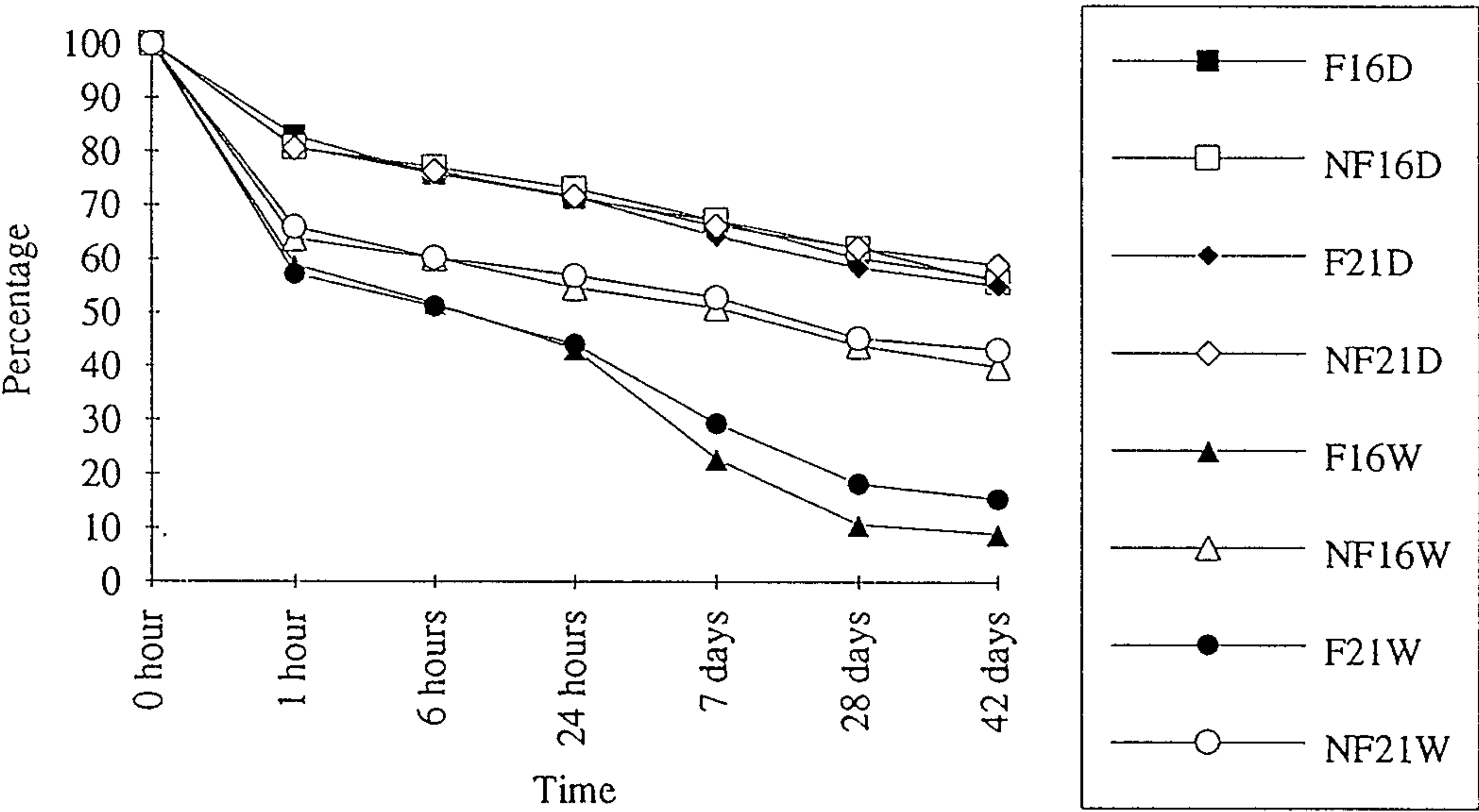


Fig. 8 Graph plots of mean percentage of initial force versus time for the elastomeric chain subsamples

Probability levels for "F" values from the ANOVA (Appendix 4) were recorded in Table 8 which demonstrates a pattern of progressive change for different test parameters involving the total period of evaluation of force degradation of the elastomeric chains.

Table 8 Probability estimates from the ANOVA for the experimental data (see Appendix 4).

	1 hour	6 hours	24 hours	7 days	28 day	42 days
Experiment 1 vs 2	-	*	*	*	**	-
F vs NF	*	**	***	***	***	***
16 vs 21 mm	-	-	-	-	*	*
D vs W condition	***	***	***	***	***	***
F/NF vs 16/21	-	-	-	-	-	-
F/NF vs D/W	**	**	***	***	***	***
16/21 vs D/W	-	-	-	**	**	*
F/NF vs 16/21 vs D/W	-	-	-	-	**	*

- P > 0.05 (non-significant)
- * P < 0.05 (significant)
- ** P < 0.01 (very significant)
- *** P < 0.001 (highly significant)

The following observations from the ANOVA are made:

1. There were mostly just significant differences for the experiment repeats for time spans of 6 hours, 24 hours, 7 days and 28 days but not at 1 hour and 42 days. That there were no significant differences at the beginning and end of the experiment for

the repeat measurements provides some reassurance concerning the reproducibility and clinical applications of the study.

2. Difference in response between F and NF elastomerics occurred at every time point, but also became progressively more significant from the first hour test onwards.

3. The elastomeric chains stretched to 16 and 21 mm showed no significant differences in performance until the last stages of the test at 28 and 42 days.

4. Throughout the total test period there was a highly significant difference between the test results under dry and wet conditions.

5. There were no significant interaction effects of the presence or absence of fluoride in the chain versus the two amounts of the test stretch (16 and 21 mm).

6. There was a significant interaction effect between the presence or absence of fluoride in the chain and the dry or wet test conditions.

7. From 7 days onwards, there was moderately significant interaction effect between the presence or absence of fluoride and the two stretch distances (16 or 21 mm) of the elastomeric chain with the dry or wet test conditions.

Tables 6 and 7 summarize the experimental mean values obtained for the force degradation for all the test samples over the several time intervals of the study, and may be viewed in conjunction with the ANOVA for the study.

With necessary reservations concerning statistical interpretations based only on mean values, Tables 6 and 7 can be seen to generally match the ANOVA:

1. At the commencement of the tests, for the same amount of stretch distance (16 or 21 mm) the F elastomerics gave slightly less force than the NF elastomerics. This pattern of difference continued throughout the tests (Table 6 and Fig. 7).
2. With all test samples under the different test conditions, there was steady degradation of force at all time points (Fig. 7 and 8).
3. The force degradation for F and NF elastomerics under dry conditions at the two amounts of stretch distance were very similar (Fig. 8).
4. Under wet conditions, the F elastomerics showed more accelerated deterioration of force from the first hour of the test up to the end of the test period at 42 days (Fig. 7 and 8).
5. Under wet test conditions the force loss of the NF elastomerics more closely matched performances in all the dry tests than did the wet test F elastomerics.

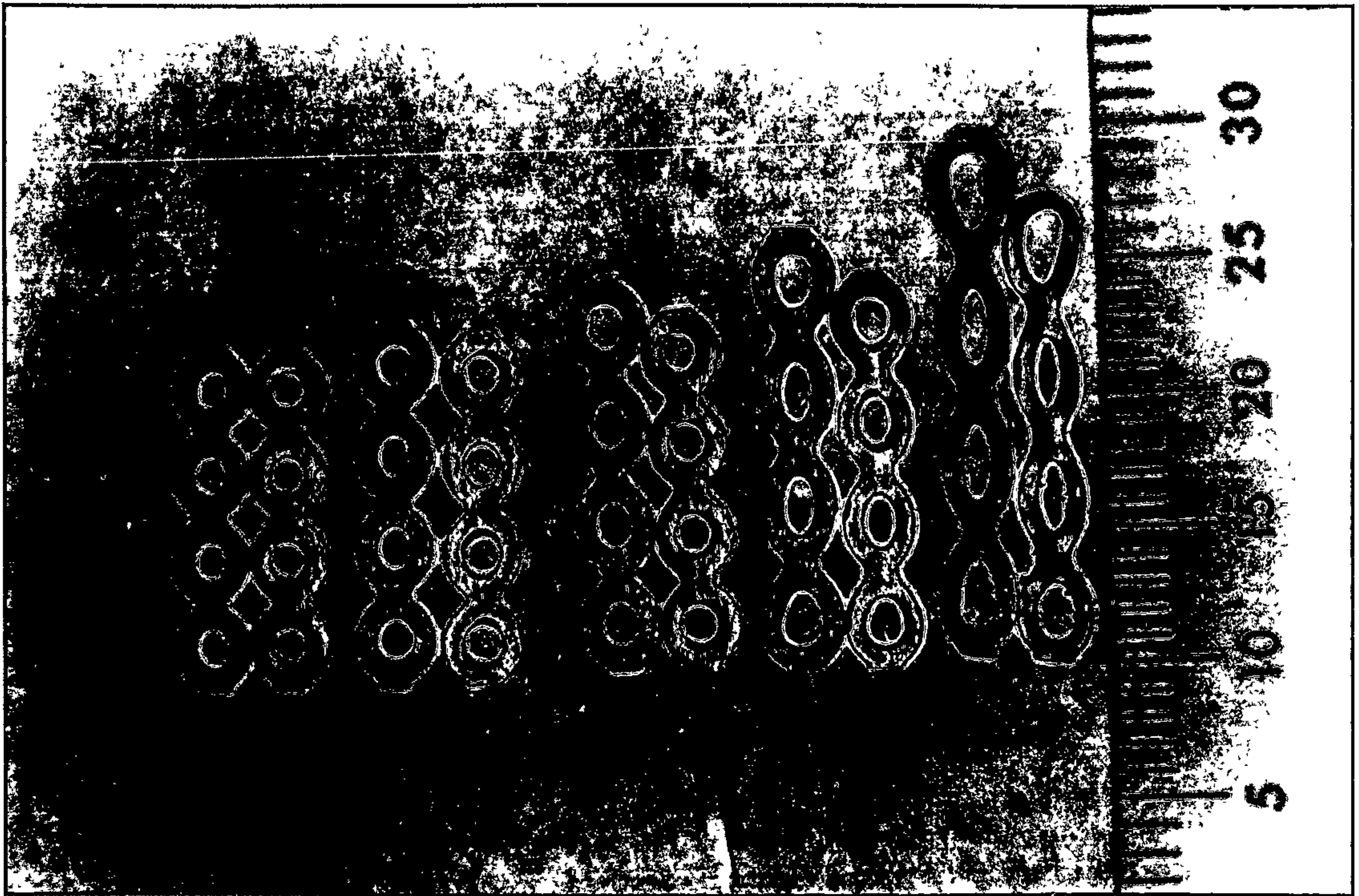


Fig. 9 Comparison of elastomeric chain in sequence from left to right : F before testing, NF before testing, then after and 42 days period testing F16D, NF16D, F21D, NF21D, F16W, NF16W, F21W, and NF21W respectively. (Note the swelling and permanent deformation of the wet samples)

3.5 Discussion

The laboratory experiments were planned to provide controls which were difficult to match in vivo, but which should, nevertheless, gave some indications of likely clinical performance of the elastomeric chain.

The significant difference between experiment 1 and 2 indicated that there possibly was some variability in elastomeric chain manufacturing. Nevertheless analysis of data from both experiments showed the same trend of force decay for the F and NF chains stretched at both distances of 16 and 21 mm, under dry and wet conditions.

The initial force magnitude ranged between 267 and 375 gram. This range of force was slightly higher than optimal force suggested by several authors for orthodontic space closure and traction for canine teeth (Smith and Storey, 1952; Reitan, 1957; Hixon et al., 1969; Boester and Johnston 1974; Young and Sandrik 1979; Quinn and Yoshikawa, 1985). These force values were chosen because they represented realistic force value that might be used in closing space.

4-link elastomeric chain was used because at both stretch distances 16 and 21 mm, they gave initial force as suggested and these distances are approximate clinical situations of space closure based on previous studies (20 mm in study by De Genova et al., 1985; 12-34 mm by Hershey and Reynolds, 1975; 14 to 48 mm by Young and Sandrik, 1979; 15 mm and 19.3 mm by Ferriter, 1990; 21 mm by Kuster et al., 1986; 22 to 40 mm by Andreasen and Bishara, 1970). The present tests used 11.5 mm lengths of the 4-link chain samples. The two stretch distances of 16 and 21 mm gave extensions of 39.1 % and 82.9 % respectively. These percentages of stretching approximated the range suggested by Rock and associates (1985) that an extension of between 50 to 70 % would provide the most satisfactory orthodontic force. The manufacturer gave no indication that prestretching of the chain is required.

Simulation with oral conditions was limited to use of a water bath 37° C in which test chain was submerged. Also in studying force degradation, it was

worthwhile monitoring the behaviour of the elastomeric chain up to 42 days which would compare with the period between appliance adjustments in clinical practice. The performances of the elastomeric chain under these test conditions were monitored at the nominated time intervals in order to study the amount and rate of expected force decay. At the end of test period 6 week, there were some active force remained but remarkably less in fluoride releasing elastomeric chain. The result showed that between 4 and 6 weeks the small force remaining did not change significantly.

The present study confirmed the general previous findings that the force of polyurethane elastomerics is soon lost after initial application and progressively reduces over longer periods of application (Andreasen and Bishara, 1970; Hershey and Reynolds, 1975; Wong, 1976; Ash and Nikolai, 1978; Brantly et al., 1979; De Genova et al., 1985; Killiany and Duplessis, 1985; Kuster et al., 1986).

The force loss of the elastomerics tested under dry conditions was consistent for both fluoride and non-fluoride containing chains, the percentage loss over 42 days being close to 50 percent. There was also agreement with Andreasen and Bishara (1970), Ash and Nikolai (1978) and Huget et al. (1990) that force degradation is significantly more rapid under wet conditions which was opposite to the observation of Bales et al. (1976). The absorption of water molecules acts to decrease the intermolecular forces of the polyurethane material (Seymour, 1984). The present study results obtained for wet condition showed that after 24 hours the initial force value reduced to approximately 50 per cent, which is similar to previous reports (Hershey and Reynolds, 1975; Wong, 1976; Killiany and Duplessis, 1985; De Genova, 1985; von Fraunhofer and Orbell, 1992).

Notably there was dramatic loss of 85 to 90 percent of the initial force for the 16 and 21 mm amounts of extension, respectively, of the fluoride chain under wet conditions by the end of the 42 days test period (Table 8 indicated that there is a very rapid and early loss of initial force). By contrast, the non-fluoride chain was more consistent at both extensions, losing just short of 60 percent of the initial force under the wet test conditions. This result indicated that the fluoride incorporation of

elastomeric chain adversely affected the elastic properties with the initial force decreasing more rapidly than occurred within the conventional elastomeric chain in the wet condition.

Nevertheless, at the end of 42 day period the elastomeric chains still had some light active force which was considered to be enough to hold the space closure as noted in the previous study by Weinstein and associates (1963). So applying fluoride-releasing elastomeric chain for space closure could be considered useful in orthodontic patients who have high caries risk as an additional source for fluoride protection.

3.6 Conclusions

The general pattern of force decay of the elastomeric chain was found to be expressed immediately after activation and continuously increased throughout the 42-days period.

This experiment revealed that the force degradation was more rapid in fluoride-releasing elastomeric chain than conventional chain. The decay in the wet condition became significantly greater than that in the dry condition after the first hour. Comparison between the two extensions (16 and 21 mm) showed no difference in force decay rate which is probably due to the percentage of extension of both being within the elastic limit of the material, so that they behaved similarly. This study implies that, because the fluoride incorporation affects the force degradation of elastomeric chain, increasing the percentage of extension to a certain level at commencement might compensate for the force loss rate and still maintain adequate activation in closing the extraction space. Further study can be made to investigate the elastic properties of the fluoride-releasing elastomeric chain to obtain maximum usefulness.

An additional factor to be considered in extension of the elastic chain is that a large extension of the chain with a resulting high initial force may not maintain the high force after a short period of time. However, there is probably more chance of permanent elongation set during the period of distraction when the chains are greatly extended at the time of initial stretching.

Although the fluoride-releasing elastomeric chain is claimed to be of benefit to reduce enamel demineralization, it remains to be proven in the oral cavity. It should not be concluded that they would perform in exactly the same way in the mouth. (Ash and Nikolai, 1978). There are several variables involved, such as pH condition (affected by saliva, and type of food and drink ingested), mastication, general oral hygiene, and amount of other available fluoride. Further study on this topic should assess in more detail the force behaviour in the oral environment.

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APPENDICES

1. DESCRIPTION OF EXPERIMENTAL APPARATUS

1) Holding elastomeric chain apparatus.

Two identical brass-stainless steel frameworks were designed to hold the sample elastic chains at stretched lengths of 16 and 21 mm between the hooks on adjustable rods and rigid lower bar. Each vertical sliding pin carrying the hook was secured at the set distance by means of a small thumb screw.

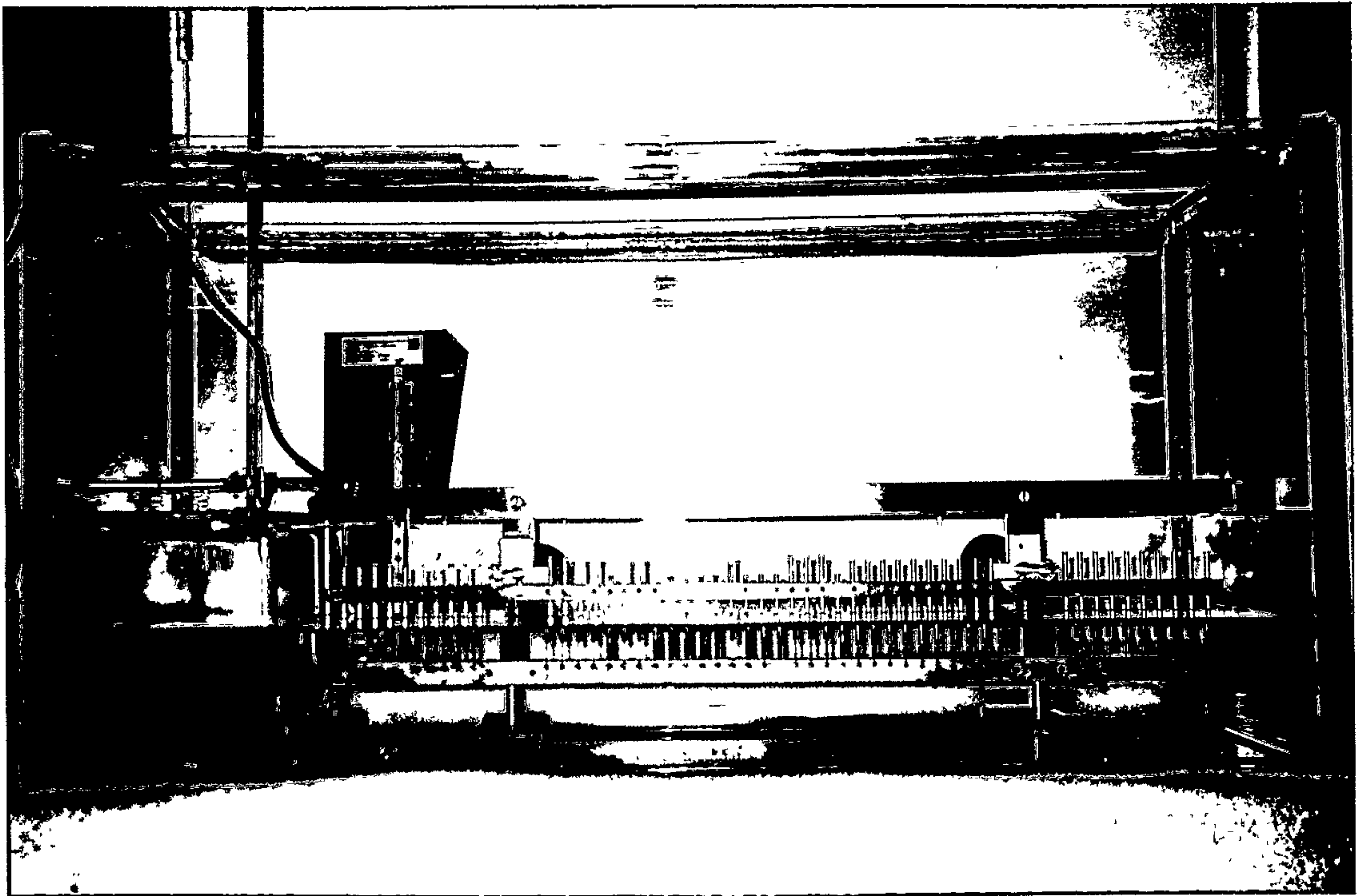


Fig. 10 Elastomeric chain test framework

2 The power source for load cell.

A rectifier circuit maintained an input direct current of 10 volts.

3 The digital Multimeter PM 2517X

The multimeter produced by Phillips was capable of registering the load cell's potential difference in millivolts and its resistance in ohms to one decimal place.

4 The electrical strain guage (load cell).

The electrical strain guage type UFI was made by the Pye/Ether Company. It has a sensing arm which undergoes minimal displacement (0.048 mm) under maximum loads (450 gs). The sensitivity of this strain gauge according to the manufacturers is 5.15 mV/V. Therefore, when the maximum recommended load measurement on the multimeter is 10 volts, the reading output would be 51.5 mV.

The strain gauge was mounted to the top bar of the apparatus. The top end of each vertical rod was connected to the strain gauge passively which was set and locked by screwing. A stretched chain elastic was then hooked from the lower bar of the framework to the bottom end of the rod. Then the rod was unscrewed to let the rod move vertically. The multimeter connected to the strain gauge while it was under load was then read in millivolts.

5 Temperature controller (Thermomix)

A "Thermomix" unit was used to circulate and maintain water bath temperature at 37° C. A plastic sheet was placed over on top of the glass tank to prevent the evaporation.

6 The glass tank.

The elastic testing frame was placed in the glass tank with held the circulating water. The test elastics were kept to provide the wet conditions the test.

7 A thermometer

A thermometer was installed to the water for checking the constant temperature of the water.

2. CALIBRATION PROCEDURE

The strain gauge was held by the vertical stand. The current from the power supply was set at 10 volts and the multimeter read in millivolts. After turning on the power for 5-10 minutes, the weight 5 g was connected to the strain gauge and the reading on the multimeter was recorded and so on with the weight 5, 10, 20, 50, 100, 150, 200, 250, 300, 350, and 400 gm. (Fig. 11)

The conversion was done using the estimate from the average over all calibrations (Table 9). The consultant statistician advised that the calibrations of grams weight against millivolts showed regression relationship which was totally linear (see summary statistical analyses p. 70 and 71).

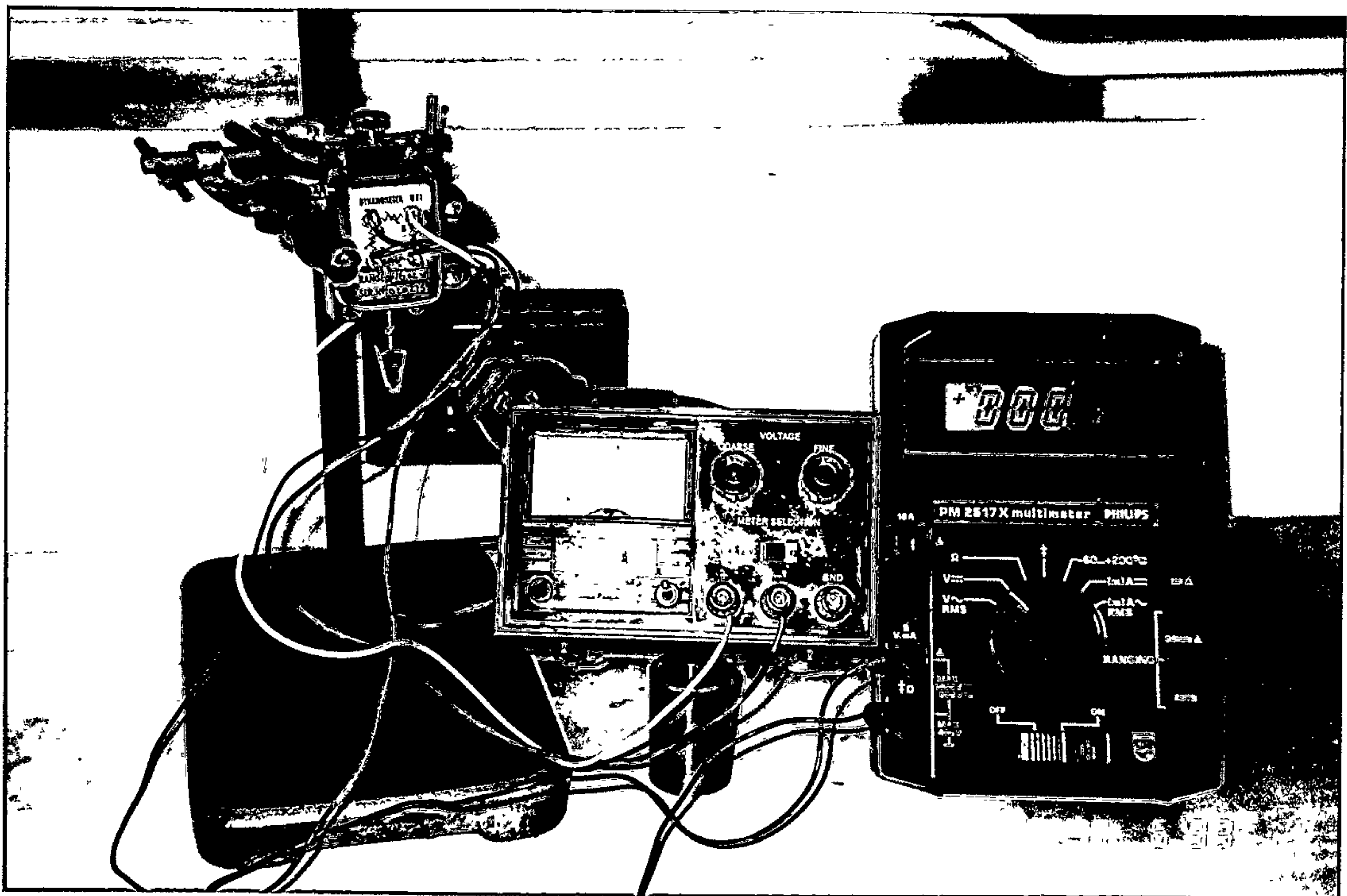


Fig. 11 Calibration procedure

Table 9 The calibration table

Weight (gram)	mV
0	0.03
5	1.19
10	1.77
20	3
50	6.69
100	12.81
150	19.01
200	25.24
250	31.43
300	37.63
350	43.81
400	50.01

QUADRATIC REGRESSION MILLIVOLTS on WEIGHT
(to justify the use of a linear regression)

MTB > let c21=c20*c20
MTB > regr c1 2 c20 c21

The regression equation is
A = - 3.33 + 7.98 C20 + 0.00184 C21

Predictor	Coef	Stdev	t-ratio	p
Constant	-3.3287	0.6909	-4.82	0.000
C20	7.97906	0.08245	96.78	0.000
C21	0.001837	0.001723	1.07	0.314

s = 1.316 R-sq = 100.0% R-sq(adj) = 100.0%

Analysis of Variance

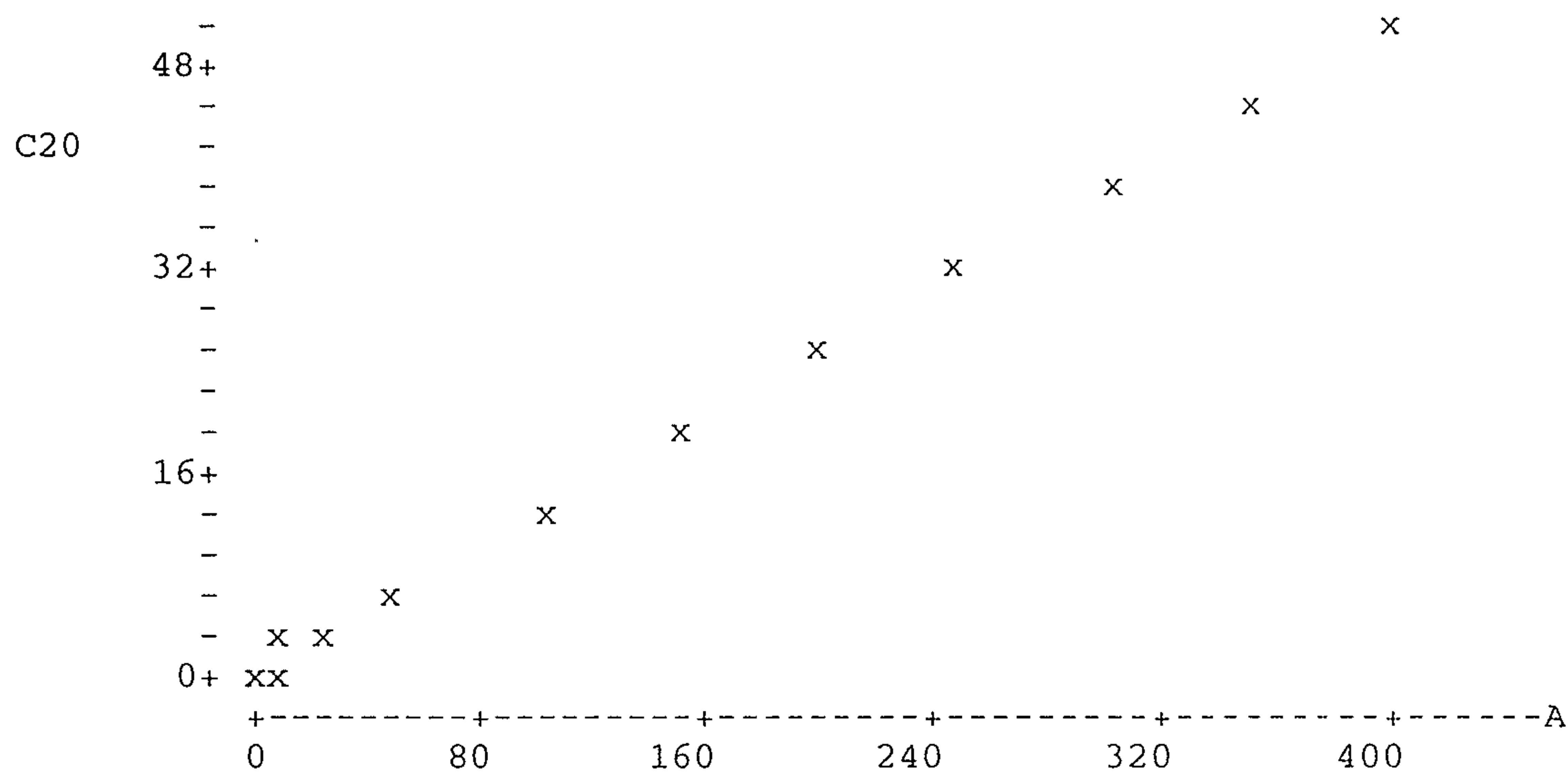
SOURCE	DF	SS	MS	F	p
Regression	2	229907	114954	66380.23	0.000
Error	9	16	2		
Total	11	229923			

SOURCE	DF	SEQ SS
linear	1	229905
quadratic	1	2

This term is non significant, and tests whether the linear regression is adequate.

PLOT OF MILLIVOLTS vs WEIGHT

MTB > Plot C20 'A';
SUBC> Symbol 'x'.



LINEAR REGRESSION WEIGHT on millivolts

MTB > regr c1 1 c20

The regression equation is
A = - 3.74 + 8.06 C20

Predictor	Coef	Stdev	t-ratio	p
Constant	-3.7390	0.5776	-6.47	0.000
C20	8.06372	0.02228	361.90	0.000

s = 1.325 R-sq = 100.0% R-sq(adj) = 100.0%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	1	229905	229905	130972.42	0.000
Error	10	18	2		
Total	11	229923			

3. RESULTS

Force degradation in gram-force and percentage

- FPC1 = force percentage hour 1
- FPC2 = force percentage hour 6
- FPC3 = force percentage hour 24
- FPC4 = force percentage day 7
- FPC5 = force percentage day 28
- FPC6 = force percentage day 42

----- Set 1: F16D -----

Variable	N	Mean	Std Dev	Minimum	Maximum
INIT	10	270.0582000	7.4265804	259.8220000	281.5840000
HOUR1	10	221.3758000	5.9477970	209.0440000	227.5820000
HOUR6	10	200.7422000	5.9234755	192.9240000	212.2680000
HOUR24	10	188.7328000	2.7345991	183.2520000	192.1180000
DAY7	10	174.6278000	3.7622927	170.3560000	180.8340000
DAY28	10	162.6184000	9.7330039	139.7280000	176.8040000
DAY42	10	152.7852000	7.6633605	137.3100000	163.1020000
FPC1	10	82.0424075	3.5271672	76.5284959	87.5915050
FPC2	10	74.3461492	1.6561274	71.7114403	76.7839546
FPC3	10	69.9315186	2.1037684	67.0826467	73.3217356
FPC4	10	64.7041411	2.1402554	60.4991761	67.1174881
FPC5	10	60.2221988	3.3927028	53.7783560	65.2562139
FPC6	10	56.5743467	2.3806238	52.8477188	59.6298679

----- Set 1: F16W -----

Variable	N	Mean	Std Dev	Minimum	Maximum
INIT	10	268.7686000	7.2535025	250.9560000	277.5540000
HOUR1	10	158.0242000	14.5975281	138.9220000	194.5360000
HOUR6	10	134.6502000	8.6479790	114.7420000	148.5940000
HOUR24	10	114.3390000	5.1434056	105.0700000	121.1900000
DAY7	10	54.9368000	7.7569794	42.2020000	63.9640000
DAY28	10	26.2432000	5.0377687	18.0220000	34.1420000
DAY42	10	20.1982000	5.5328376	12.3800000	27.6940000
FPC1	10	58.8079899	5.4164917	54.6478272	73.0596763
FPC2	10	50.0579255	2.0781656	45.7219592	53.5369694
FPC3	10	42.5406692	1.5114357	40.7161140	45.7911720
FPC4	10	20.3949479	2.4828780	16.1520261	23.0456055
FPC5	10	9.7344413	1.6908386	7.1813386	12.3010297
FPC6	10	7.4934120	1.9552903	4.5664795	9.9778782

----- Set 1: F21D -----

Variable	N	Mean	Std Dev	Minimum	Maximum
INIT	10	337.3592000	10.0941467	318.6600000	350.0940000
HOUR1	10	266.9148000	5.1511185	257.4040000	271.9120000
HOUR6	10	249.8276000	3.1606895	244.5080000	254.1800000
HOUR24	10	236.6092000	6.0768575	222.7460000	243.7020000
DAY7	10	214.2024000	6.2916204	199.3720000	224.3580000
DAY28	10	193.0852000	11.1734329	170.3560000	206.6260000
DAY42	10	181.5594000	15.3137643	146.9820000	205.0140000
FPC1	10	79.1591108	1.9647902	76.7473878	84.0651478
FPC2	10	74.1008547	1.9247784	71.6824624	78.2476621
FPC3	10	70.1846232	2.5213596	64.6667751	73.9477813
FPC4	10	63.5124163	1.5904259	61.4638923	66.0622586
FPC5	10	57.2302604	2.7868643	52.2864478	60.8410676
FPC6	10	53.7889896	3.9220762	46.1250235	60.3664138

----- Set 1: F21W -----

Variable	N	Mean	Std Dev	Minimum	Maximum
INIT	8	332.6642500	9.5068716	320.2720000	344.4520000
HOURL1	8	178.4160000	8.4424137	162.2960000	188.8940000
HOURL6	8	159.0720000	6.1984941	149.4000000	169.5500000
HOURL24	8	139.2242500	3.4983822	134.8920000	142.9520000
DAY7	8	91.9725000	5.6625239	83.3080000	103.4580000
DAY28	8	53.3852500	6.9926182	38.9780000	61.5460000
DAY42	8	47.4410000	6.7020660	33.3360000	55.0980000
FPC1	8	53.6553417	2.6395686	49.9206418	56.6806676
FPC2	8	47.8381287	1.9755626	45.8007099	50.9214500
FPC3	8	41.8710103	1.2422116	39.4381845	43.4094270
FPC4	8	27.6868981	2.1918617	24.3566429	31.8226559
FPC5	8	16.0421306	2.0378786	11.9892467	18.4618075
FPC6	8	14.2590538	1.9799417	10.2538233	16.1968577

----- Set 1: NF16D -----

Variable	N	Mean	Std Dev	Minimum	Maximum
INIT	10	304.1520000	9.2133474	288.8380000	313.0180000
HOURL1	10	246.7648000	7.5399183	237.2540000	255.7920000
HOURL6	10	234.9166000	10.5668345	218.7160000	254.9860000
HOURL24	10	222.1818000	9.2839787	209.0440000	241.2840000
DAY7	10	206.4648000	6.7198899	196.1480000	218.7160000
DAY28	10	188.2492000	11.1540357	166.3260000	201.7900000
DAY42	10	175.5144000	14.4091521	156.6540000	200.9840000
FPC1	10	81.1544687	2.0052615	77.5980934	83.3960502
FPC2	10	77.2215176	1.9805192	74.4978308	81.4604911
FPC3	10	73.0441645	1.8485725	70.5541964	77.0831070
FPC4	10	67.8910077	1.3961422	66.4376973	71.1558482
FPC5	10	61.9048811	3.4481640	56.0942036	66.5153679
FPC6	10	57.6993000	4.2875373	51.5912823	65.5589262

----- Set 1: NF16W -----

Variable	N	Mean	Std Dev	Minimum	Maximum
INIT	10	289.5634000	13.2844732	271.1060000	308.9880000
HOURL1	10	184.6222000	14.1556997	151.8180000	198.5660000
HOURL6	10	176.1592000	5.7220324	168.7440000	185.6700000
HOURL24	10	158.9914000	7.5365669	148.5940000	174.3860000
DAY7	10	146.4984000	4.5148792	139.7280000	154.2360000
DAY28	10	123.7692000	7.2669243	112.3240000	134.8920000
DAY42	10	118.0466000	10.3109912	103.4580000	134.8920000
FPC1	10	63.8579064	5.5133737	54.0704756	71.5007473
FPC2	10	60.9393794	3.1749387	56.3085873	66.5060329
FPC3	10	54.9453344	2.2384159	51.2207594	59.7085550
FPC4	10	50.6698255	2.3416196	45.2211736	53.2092970
FPC5	10	42.8251246	3.1349938	36.3522208	46.1860838
FPC6	10	40.8593342	4.1878861	35.0479630	48.1805323

----- Set 1: NF21D -----

Variable	N	Mean	Std Dev	Minimum	Maximum
INIT	10	381.9310000	18.8191363	338.8100000	396.0360000
HOURL1	10	304.1520000	14.1605430	271.9120000	320.2720000
HOURL6	10	289.1604000	7.0797618	276.7480000	301.7340000
HOURL24	10	269.6552000	12.8106397	248.5380000	288.8380000
DAY7	10	250.5530000	7.4865981	236.4480000	262.2400000
DAY28	10	236.9316000	8.7735197	222.7460000	252.5680000
DAY42	10	223.1490000	14.1923659	194.5360000	242.0900000
FPC1	10	79.7709136	4.6366353	69.9394519	87.3917535
FPC2	10	75.8186939	2.6961381	72.8770589	81.6823588
FPC3	10	70.7087738	3.9098275	63.7950861	77.8760957
FPC4	10	65.7793128	4.4075944	59.8254181	74.3077241
FPC5	10	62.1488723	3.3503618	57.1747590	68.1225466
FPC6	10	58.5164895	4.2189527	53.7689502	67.6467637

----- Set 1: NF21W -----

Variable	N	Mean	Std Dev	Minimum	Maximum
INIT	10	360.7332000	21.3003705	325.1080000	392.0060000
HOURL1	10	235.7226000	6.5308661	228.3880000	246.1200000
HOURL6	10	212.1874000	12.1016366	180.8340000	227.5820000
HOURL24	10	203.1602000	8.2812986	184.8640000	214.6860000
DAY7	10	188.0074000	8.0908377	171.9680000	197.7600000
DAY28	10	157.4600000	20.8316309	121.9960000	188.8940000
DAY42	10	152.6240000	14.2165037	130.0560000	170.3560000
FPC1	10	65.5457517	4.2793234	61.8629462	75.7040737
FPC2	10	58.9538611	4.1204252	51.2986792	65.2915339
FPC3	10	56.4508002	3.3189521	51.6362502	63.0602754
FPC4	10	52.2056883	2.3918003	49.4201619	56.5691840
FPC5	10	43.6491429	5.1549999	33.6834316	50.4164770
FPC6	10	42.3310436	3.4463961	38.2950155	49.4248065

----- Set 2: F16D -----

Variable	N	Mean	Std Dev	Minimum	Maximum
INIT	10	264.0132000	8.3052337	251.7620000	278.3600000
HOURL1	10	220.7310000	4.5475355	214.6860000	230.8060000
HOURL6	10	204.3692000	5.6586073	197.7600000	213.8800000
HOURL24	10	192.2792000	5.2757268	183.2520000	204.2080000
DAY7	10	183.6550000	5.1992380	172.7740000	189.7000000
DAY28	10	159.6362000	10.4196263	136.5040000	167.1320000
DAY42	10	149.8836000	4.9568818	140.5340000	157.4600000
FPC1	10	83.6447304	1.7925921	80.3103894	86.5539676
FPC2	10	77.4491771	2.3958118	74.5731776	82.7122441
FPC3	10	72.8685810	2.2358709	68.8218725	75.1007679
FPC4	10	69.6020224	2.2946950	66.7013939	73.7482225
FPC5	10	60.4491852	3.2542935	54.2194612	64.6167115
FPC6	10	56.7911295	1.6952030	54.4262422	59.6619029

----- Set 2: F16W -----

Variable	N	Mean	Std Dev	Minimum	Maximum
INIT	10	260.8698000	10.8339646	244.5080000	274.3300000
HOURL1	10	153.8330000	3.7661279	148.5940000	161.4900000
HOURL6	10	138.8414000	5.2296917	128.4440000	145.3700000
HOURL24	10	114.3390000	3.8420273	109.1000000	120.3840000
DAY7	10	66.5432000	3.3728101	61.5460000	71.2180000
DAY28	10	30.7568000	3.7766545	22.0520000	35.7540000
DAY42	10	27.6134000	2.0966331	24.4700000	30.9180000
FPC1	10	59.0396370	2.2798297	55.6351839	61.5809945
FPC2	10	53.2962268	2.8091706	49.3081761	57.2376548
FPC3	10	43.8779230	1.8771942	41.0978513	47.0257515
FPC4	10	25.5500117	1.6979301	22.7695154	27.8084971
FPC5	10	11.8152159	1.5541703	8.1583426	13.6339097
FPC6	10	10.6212457	1.1488712	9.0529042	12.6449850

----- Set 2: F21D -----

Variable	N	Mean	Std Dev	Minimum	Maximum
INIT	10	319.8690000	11.5448539	300.9280000	333.9740000
HOURL1	10	263.6102000	6.9339947	252.5680000	273.5240000
HOURL6	10	247.6514000	5.6796159	238.8660000	255.7920000
HOURL24	10	233.5464000	6.6811085	223.5520000	243.7020000
DAY7	10	208.4798000	7.3876006	200.1780000	226.7760000
DAY28	10	191.7956000	5.7522280	184.0580000	200.1780000
DAY42	10	180.7534000	8.5082962	167.1320000	195.3420000
FPC1	10	82.4852026	2.9964865	75.6250487	86.5207668
FPC2	10	77.4883340	2.5634650	73.6943594	82.2919877
FPC3	10	73.0604415	2.2382856	70.5104590	76.4302425
FPC4	10	65.2379083	2.8883940	59.9381988	68.6629360
FPC5	10	60.0264333	2.7047582	56.0768204	65.1810400
FPC6	10	56.5351918	2.4823088	52.4567781	60.3846725

----- Set 2: F21W -----

Variable	N	Mean	Std Dev	Minimum	Maximum
INIT	10	307.8596000	24.9735747	249.3440000	339.6160000
HOURL1	10	187.4432000	5.9326078	174.3860000	193.7300000
HOURL6	10	168.3410000	9.0493219	146.1760000	177.6100000
HOURL24	10	143.8386000	5.8548379	134.0860000	150.2060000
DAY7	10	96.4458000	3.2474232	92.9800000	101.0400000
DAY28	10	63.3192000	7.1568282	51.8740000	72.8300000
DAY42	10	51.9546000	6.9068761	38.1720000	59.9340000
FPC1	10	61.2494791	5.4562939	57.0438377	75.4331366
FPC2	10	55.0273998	5.7723016	49.3684395	69.6146689
FPC3	10	46.9975777	4.3499340	43.9706190	58.6242300
FPC4	10	31.5281337	2.9503866	28.7422410	38.5828414
FPC5	10	20.7032849	3.0246931	16.5337438	26.9459061
FPC6	10	17.0325904	3.0487983	11.7998368	22.7436794

----- Set 2: NF16D -----

Variable	N	Mean	Std Dev	Minimum	Maximum
INIT	10	311.2448000	16.3811775	281.5840000	332.3620000
HOURL1	10	249.7470000	5.3227200	242.8960000	260.6280000
HOURL6	10	238.3018000	6.3697235	230.0000000	248.5380000
HOURL24	10	228.3074000	7.5269833	213.0740000	240.4780000
DAY7	10	207.6738000	4.1282100	202.5960000	214.6860000
DAY28	10	194.5360000	7.8236914	183.2520000	205.8200000
DAY42	10	168.5828000	12.0379457	155.8480000	189.7000000
FPC1	10	80.4089048	3.8260886	75.2722427	86.5468208
FPC2	10	76.7208635	3.7846060	71.2758375	82.2532530
FPC3	10	73.5953408	5.5119847	66.1958967	82.2532530
FPC4	10	66.9304472	4.5201264	61.1989337	76.2422581
FPC5	10	62.6684166	4.2413573	55.6212804	67.3688846
FPC6	10	54.3933925	5.9313757	47.1335472	64.9519623

----- Set 2: NF16W -----

Variable	N	Mean	Std Dev	Minimum	Maximum
INIT	10	291.9814000	8.4572409	279.9720000	302.5400000
HOUR1	10	186.9596000	7.8255364	171.9680000	196.1480000
HOUR6	10	173.5800000	4.7607855	165.5200000	180.0280000
HOUR24	10	158.6690000	3.9531449	151.0120000	163.9080000
DAY7	10	150.5284000	6.5059507	141.3400000	161.4900000
DAY28	10	131.8292000	10.2643326	108.2940000	141.3400000
DAY42	10	115.4674000	10.9624560	96.2040000	132.4740000
FPC1	10	64.0602020	2.8315878	60.8124302	68.3042611
FPC2	10	59.4777512	1.8755394	56.3423809	63.2103031
FPC3	10	54.3722760	1.7424254	51.7054598	57.5503497
FPC4	10	51.5837672	2.4594399	47.7715600	55.0033707
FPC5	10	45.2187880	4.1372939	35.7949362	49.6264150
FPC6	10	39.5717729	3.8192349	31.7987704	44.8629464

----- Set 2: NF21D -----

Variable	N	Mean	Std Dev	Minimum	Maximum
INIT	10	369.0350000	9.5461770	354.9300000	382.3340000
HOUR1	10	300.2026000	8.9062088	285.6140000	313.8240000
HOUR6	10	283.7602000	10.0457625	267.0760000	298.5100000
HOUR24	10	268.7686000	10.6349249	254.1800000	284.0020000
DAY7	10	246.6036000	4.6565444	238.0600000	252.5680000
DAY28	10	230.6448000	9.1172658	209.0440000	238.8660000
DAY42	10	220.0862000	11.1944086	196.9540000	236.4480000
FPC1	10	81.3858185	2.8570449	76.3114723	85.6938420
FPC2	10	76.9117234	2.6052061	73.2965688	81.6922454
FPC3	10	72.8338441	2.3048690	69.4202643	76.0818921
FPC4	10	66.8632905	2.0906461	62.2649307	69.4127105
FPC5	10	62.5513511	3.2755678	56.0947990	67.1469854
FPC6	10	59.7047071	3.9497874	52.8505724	65.1078328

----- Set 2: NF21W -----

Variable	N	Mean	Std Dev	Minimum	Maximum
INIT	10	356.4614000	16.0277175	332.3620000	384.7520000
HOUR1	10	237.3346000	10.6077412	217.1040000	248.5380000
HOUR6	10	220.6504000	10.0036402	203.4020000	231.6120000
HOUR24	10	205.4170000	5.2681964	195.3420000	211.4620000
DAY7	10	192.0374000	7.8462627	175.1920000	204.2080000
DAY28	10	168.1798000	9.2372117	150.2060000	184.8640000
DAY42	10	157.2988000	6.7946645	146.9820000	167.9380000
FPC1	10	66.6669322	3.5327869	59.0235601	71.6202138
FPC2	10	62.0171925	4.0467969	55.9558052	67.7311253
FPC3	10	57.7270309	2.9066024	54.2028024	62.1689604
FPC4	10	53.9463326	2.8155490	49.4719364	59.0163737
FPC5	10	47.2532739	3.1628354	42.3198941	52.7112004
FPC6	10	44.1745476	2.0615600	40.8361562	46.9356283

Summary : Mean percentage of experiment 1 and 2

Dependent Variable: FPC1

F/NF	Distance	Condition	N	Mean	SD
F	16	D	2	82.8435690	1.13301342
F	16	W	2	58.9238134	0.16379918
F	21	D	2	80.8221567	2.35190204
F	21	W	2	57.4524104	5.36986602
NF	16	D	2	80.7816868	0.52719326
NF	16	W	2	63.9590542	0.14304459
NF	21	D	2	80.5783660	1.14191016
NF	21	W	2	66.1063419	0.79279428

Dependent Variable: FPC2

F/NF	Distance	Condition	N	Mean	SD
F	16	D	2	75.8976631	2.19417206
F	16	W	2	51.6770761	2.28982479
F	21	D	2	75.7945943	2.39530960
F	21	W	2	51.4327643	5.08358237
NF	16	D	2	76.9711906	0.35401592
NF	16	W	2	60.2085653	1.03352721
NF	21	D	2	76.3652086	0.77288853
NF	21	W	2	60.4855268	2.16610244

Dependent Variable: FPC3

F/NF	Distance	Condition	N	Mean	SD
F	16	D	2	71.4000498	2.07681676
F	16	W	2	43.2092961	0.94558125
F	21	D	2	71.6225324	2.03351059
F	21	W	2	44.4342940	3.62503053
NF	16	D	2	73.3197526	0.38974053
NF	16	W	2	54.6588052	0.40521350
NF	21	D	2	71.7713089	1.50265166
NF	21	W	2	57.0889155	0.90243138

Dependent Variable: FPC4

F/NF	Distance	Condition	N	Mean	SD
F	16	D	2	67.1530817	3.46332509
F	16	W	2	22.9724798	3.64518059
F	21	D	2	64.3751623	1.22010711
F	21	W	2	29.6075159	2.71616373
NF	16	D	2	67.4107274	0.67921882
NF	16	W	2	51.1267963	0.64625434
NF	21	D	2	66.3213016	0.76648793
NF	21	W	2	53.0760104	1.23082137

Dependent Variable: FPC5

F/NF	Distance	Condition	N	Mean	SD
F	16	D	2	60.3356920	0.16050361
F	16	W	2	10.7748286	1.47132982
F	21	D	2	58.6283469	1.97719282
F	21	W	2	18.3727077	3.29593382
NF	16	D	2	62.2866488	0.53990108
NF	16	W	2	44.0219563	1.69257568
NF	21	D	2	62.3501117	0.28459545
NF	21	W	2	45.4512084	2.54850544

Dependent Variable: FPC6

F/NF	Distance	Condition	N	Mean	SD
F	16	D	2	56.6827381	0.15328861
F	16	W	2	9.0573288	2.21171246
F	21	D	2	55.1620907	1.94185818
F	21	W	2	15.6458221	1.96118655
NF	16	D	2	56.0463462	2.33762964
NF	16	W	2	40.2155536	0.91044334
NF	21	D	2	59.1105983	0.84019672
NF	21	W	2	43.2527956	1.30355421

4. THE ANALYSIS OF VARIANCE PROCEDURE

Force percentage analysis

DF	= degrees of freedom
Anova SS	= Anova sum of squares
F Value	= force value
Pr > F	= probability significance
*	= interaction relationship
EXP	= experiment 1 interaction experiment 2
FLOU	= flouride/non-fluoride
DIST	= distance (16/21mm)
COND	= condition (dry/wet)

Dependent Variable: FPC1

Source	DF	Anova SS	Mean Square	F Value	Pr > F
EXP	1	13.96333	13.96333	4.08	0.083
FLOU	1	32.39601	32.39601	9.47	0.017
DIST	1	0.59973	0.59973	0.18	0.688
COND	1	1543.86749	1543.86749	451.33	0.000
FLOU*DIST	1	7.38965	7.38965	2.16	0.185
FLOU*COND	1	63.95877	63.95877	18.70	0.003
DIST*COND	1	2.10340	2.10340	0.61	0.458
FLOU*DIST*COND	1	0.81054	0.81054	0.24	0.641
Error	7	23.94500	3.42071		

Dependent Variable: FPC2

Source	DF	Anova SS	Mean Square	F Value	Pr > F
EXP	1	22.82966	22.82966	6.32	0.040
FLOU	1	92.43278	92.43278	25.58	0.001
DIST	1	0.11438	0.11438	0.03	0.863
COND	1	1649.36396	1649.36396	456.50	0.000
FLOU*DIST	1	0.00008	0.00008	0.00	0.996
FLOU*COND	1	63.52178	63.52178	17.58	0.004
DIST*COND	1	0.13753	0.13753	0.04	0.850
FLOU*DIST*COND	1	0.26224	0.26224	0.07	0.795
Error	7	25.29121	3.61303		
Corrected Total	15	1853.95361			

Dependent Variable: FPC3

Source	DF	Anova SS	Mean Square	F Value	Pr > F
EXP	1	15.31963	15.31963	10.16	0.015
FLOU	1	171.25138	171.25138	113.60	0.000
DIST	1	1.35623	1.35623	0.90	0.374
COND	1	1967.91309	1967.91309	1305.4	0.000
FLOU*DIST	1	0.08004	0.08004	0.05	0.824
FLOU*COND	1	121.39248	121.39248	80.53	0.000
DIST*COND	1	6.20276	6.20276	4.11	0.082
FLOU*DIST*COND	1	2.21420	2.21420	1.47	0.264
Error	7	10.55211	1.50744		
Corrected Total	15	2296.28192			

Dependent Variable: FPC4

Source	DF	Anova SS	Mean Square	F Value	Pr > F
EXP	1	21.15465	21.15465	9.27	0.018
FLOU	1	724.32561	724.32561	317.39	0.000
DIST	1	5.56230	5.56230	2.44	0.162
COND	1	2941.84041	2941.84041	1289.0	0.000
FLOU*DIST	1	2.24599	2.24599	0.98	0.354
FLOU*COND	1	610.56003	610.56003	267.54	0.000
DIST*COND	1	38.76056	38.76056	16.98	0.004
FLOU*DIST*COND	1	10.15797	10.15797	4.45	0.072
Error	7	15.97492	2.28213		
Corrected Total	15	4370.58245			

Dependent Variable: FPC5

Source	DF	Anova SS	Mean Square	F Value	Pr > F
EXP	1	17.91172	17.91172	14.27	0.006
FLOU	1	1088.94555	1088.94555	867.83	0.000
DIST	1	13.62809	13.62809	10.86	0.013
COND	1	3905.00625	3905.00625	3112.0	0.000
FLOU*DIST	1	4.83520	4.83520	3.85	0.090
FLOU*COND	1	746.73505	746.73505	595.11	0.000
DIST*COND	1	28.46763	28.46763	22.69	0.002
FLOU*DIST*COND	1	15.75866	15.75866	12.56	0.009
Error	7	8.78350	1.25479		
Corrected Total	15	5830.07166			

Dependent Variable: FPC6

Source	DF	Anova SS	Mean Square	F Value	Pr > F
EXP	1	3.33301	3.33301	1.30	0.291
FLOU	1	963.39823	963.39823	376.79	0.000
DIST	1	31.18854	31.18854	12.20	0.010
COND	1	3530.15846	3530.15846	1380.6	0.000
FLOU*DIST	1	0.26711	0.26711	0.10	0.756
FLOU*COND	1	768.76109	768.76109	300.67	0.000
DIST*COND	1	16.33021	16.33021	6.39	0.039
FLOU*DIST*COND	1	16.54924	16.54924	6.47	0.038
Error	7	17.89783	2.55683		
Corrected Total	15	5347.88371			