THE PROPERTIES OF VARIOUS SEALING MEMBRANES AND COATINGS USED FOR CONTROLLED ATMOSPHERE GRAIN STORES

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ABSTRACT

This paper describes the work undertaken by the Gardner Perrott Group in investigating consistent types of failure of sealants and coatings used in sealing operational grain stores. Failures mostly occurred at lap joints between cladding sheets, or similar joints and overlaps where mechanical forces were imposed on the sealants through movement of the structural components. The ideal sealant properties are described; in particular the ability of the sealant or film to peel off the substrate in preference to breaking so that the tensile strength should be greater than the adhesive strength. A series of tests were carried out on common sealants, coatings and foams to determine their suitability in practice. It is concluded that PVC coatings used on their own will peel, but have poor elongation properties and need top coatings to give protection from UV-radiation. Acrylic coatings, if used alone, need reinforcement to increase tensile strength. A combination of the two systems is possible provided that the tensile strength of the films is greater than the peel strength and that PVC films in a combination should always be weaker than the associated acrylic film. If carefully chosen all the films under test were considered suitable for sealing grain stores.

INTRODUCTION

The Gardner Perrott Group has been involved in silo sealing technology since the first attempts were made to seal operational grain stores. Many of the techniques were developed in the earlier programmes, for example the sealing of the horizontal storage silo at Harden in New South Wales. During this period the CSIRO and various state grain storage and handling authorities have developed criteria which they believe sealants should meet under test conditions before they can be considered for use as sealants in the field. The test criteria were most relevant to the vertical concrete silo.

In 1982 a series of contracts for the sealing of grain stores owned by Co-operative Bulk Handling were put out to tender and the Gardner Perrott Group was awarded the contract for sealing nine stores, located at Beacon, Nembudding, Bencubbin, Kodj Kodjin, Bodallin, Doodlakine, Shackleton and Hyden. All the stores except Kodj Kodjin were "A" type stores, while the Kodj Kodjin was a "G" type store *.

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* "A" type stores are framed buildings with concrete walls, concrete floor, concrete or steel portal frames, or concrete steel columns with warren or similar trusses, corrugated galvanised sheet steel roof cladding.

* "G" type stores are generally steel framed buildings with walls of A shaped timber frames sheeted internally with corrugated sheet steel, the corrugations running horizontally. The floor is compacted hardcore with an asphalt surface. Roof cladding is corrugated galvanised sheet steel.

There was some significant differences between the specifications for the Harden and CBH stores, for example in Western Australia external foaming was not allowed and this necessitated a change in the method of sealing end laps of sheets. New techniques were required and these were rapidly developed and applied without difficulty. In the case of the sheet end laps the techniques developed and tested were:

double taped putty films
sand acrylic grout
foam rubber saturated with acrylic

The most uniformly suitable technique was the use of foam rubber with acrylic.

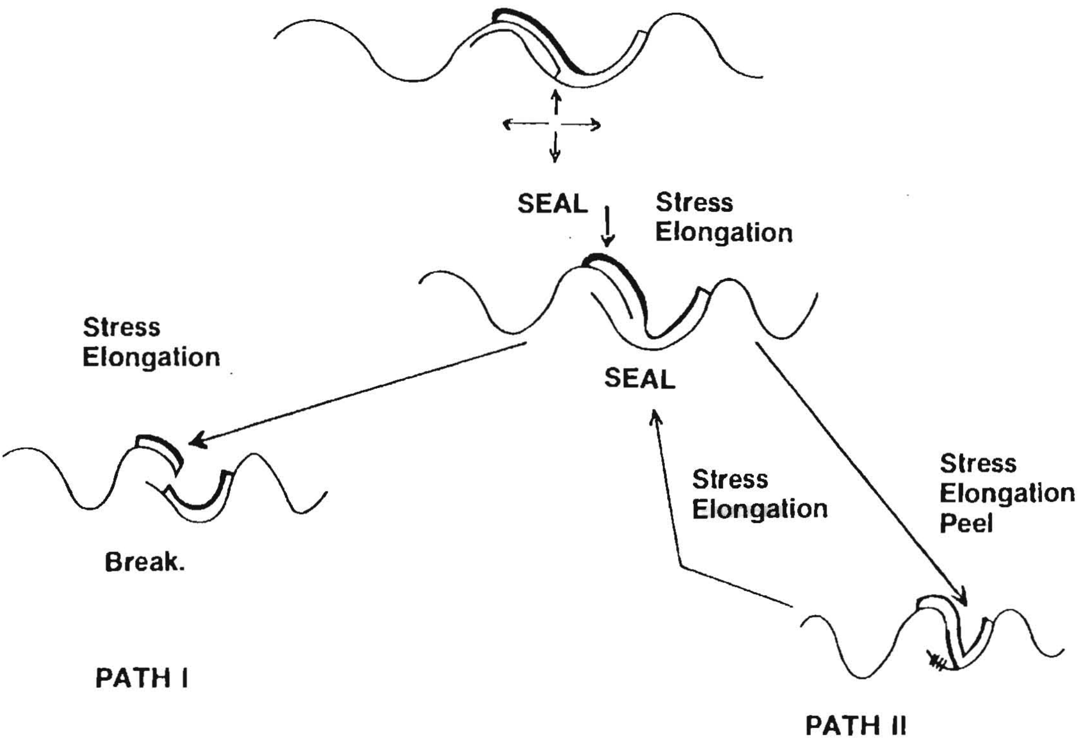
There were however some apparently consistent types of failures associated with corrugated sheet steel lap joints on roofs and walls. We embarked on a failure analysis study of stores which showed these failures.

It became apparent that the failure on lap seals is a common problem. One way in which the Gardner Bros. & Perrott specification overcame this was to reinforce the film with glass fibre or synthetic fibre mesh sealant. This has proved successful particularly in such difficult locations as sealing the flashing bridging the gap between the wall and the roof where movement due to mechanical forces is a common phenomenon. In some cases the reinforced film peels away from the wall in attempting to accommodate wall movement.

An analysis of the lap failure mechanism is presented in Figure 1 and indicates that two possible pathways can occur; one which will certainly lead to failure or seal breakdown and the other which will probably retain the integrity of the seal. The sequence of events of Pathway I is the elongation of the bridging sealant beyond its tensile and elastic limits until breaking of the film or sealant occurs. Pathway II is a cyclical series of events in which peeling of the sealant adjacent to the lap takes place before the tensile strength of the film is exceeded. This can theoretically continue until peeling has reached the edge of the sealant furthest from the lap.

FIGURE 1

ELONGATION. Pathways for Lap Joints.



ANALYSIS OF SEALANT PROPERTIES

In our analysis of the sealant films and foams, we felt a clear statement of objective and terms of reference needed to be made:

1. No sealant, film or foam used in normal commercial thicknesses can withstand the forces which cause the movement of the silo structure. They must yield or break.

2. The ideal material should have:

   I. Maximum elasticity
   II. Excellent gap bridging properties
   III. Tensile strength greater than adhesive strength, that is peel in preference to break
   IV. Maximum tear resistance
   V. For external use, UV and weather resistance.

The physical properties which we then defined as essential to measure under controlled conditions were:

(a) Tensile strength
(b) Percentage elongation at break
(c) Tear strength
(d) Adhesive or peel strength.

The method of measuring tensile strength and per cent elongation is described in ASTM D882. We carried out each measurement only in duplicate whereas ASTM D882 requires ten replicates. However, we feel our abbreviated tests were satisfactory for the purposes of this study.

For the tear strength tests, films were prepared as required in ASTM D882 by drawing out wet films on glass, curing, cutting into 25mm strips, and peeling from the glass. A variable which we need to acknowledge is that we cannot be absolutely sure all films were totally cured. We were reasonably confident they were cured by allowing films to cure for several days on the glass plate and then allowed several more days cure after peeling from the glass. We believe that, since we did not observe large differences in tensile strength versus thickness, that we achieved total cure. Tests were carried out at 350, 700 and 1,500 microns dry film thickenss at $0^{\circ}C$, $25^{\circ}C$ and $50^{\circ}C$.

The adhesive strength of films to new and old galvanised sheet steel plate was measured by drawing out a 1,000 micron thick film over the plate, half of which was covered by plastic coated paper. The films were cured and 180° peel tests were carried out using the tensile testing apparatus. Several of the films broke rather than peeled and so the procedure was repeated with reinforcing fabric so that a peeling mode was achieved.

Tensile and per cent elongation tests on foams were carried out on the same apparatus as for films. Tear strength was considered irrelevant. Adhesive strengths were measured in a compressive, shear mode for a 25mm wide strip compressed at a constant speed and the force needed to cause peeling on the 25mm face was measured.

Per Cent Elongation of Films

Maximum elasticity before break is a prime requisite of a sealant film. The results of elongation tests are depicted in Figures 2, 3 and 4. it will be seen that the polychloroprene type film gave the best performance followed by the acrylic coatings and then the PVC coatings. No judgement can be made as to what is a satisfactory elongation. Our belief, which is made evident later, is that if properly specified, all the coating systems tested will perform satisfactorily. However, elongation cannot be considered in isolation. In Figure 5 a graph of elongation versus temperature shows that most coatings lose elasticity with increasing temperature. The variant on this was the Envelon which becomes more elastic. Two possible explanations for decreased elasticity with increasing temperature are a more complete cure or loss of volatiles from the film.

Tensile Strength of Films

To the extent that no sealant will resist the forces applied to them by movement of the structure, its tensile strength cannot be considered in comparison to the strength of structural components. The ideal characteristic would be for there to be no significant change in tensile strength with variations in thickness of film or temperature.

Tests of tensile strength with respect to thickness of film at different temperatures are illustrated in Figures 6, 7 and 8. It is readily apparent that the acrylic and polychloroprene films possess the ideal characteristic while the PVC coatings less so. The Elascote at 50°C has a dramatically increased tensile strength shown in Figure 9. The increase in tensile strength of the Elascote correlates with the reduced elongation at higher temperatures shown in Figure 5.

Tear Properties of Films

The most important aspect of tear susceptibility of films is the reduction in desirable properties such as elongation and tensile strength when the film is cut. Table 1 shows the elongation (ER) and tensile strength (SR) ratios for the cut and uncut test strips. The PVC films are similar to each other, while the acrylics are different to the pVC;s but similar to each other also. The PVC films have less reduction in elongation, but greater reduction in tensile strength. The polychloroprene shows different characteristics to both in that its strength shows neglible sensitivity to cutting, but the elongation sensitivity is markedly affected by temperature.

Table 1 – Elongation and tensile strength (tear/tensile ratios)

Material	Thickness mm	Temperature °C					
		0		25		50	
		ER	SR	ER	SR	ER	SR
Gaseal	300	0.31	0.61	0.26	0.60	0.24	0.65
	600	0.34	0.46	0.31	0.48	0.30	0.50
	1,500	0.45	0.64	0.45	0.69	0.43	0.45
Flexacryl	330	0.27	0.95	0.28	0.95	0.31	0.94
	650	0.27	0.85	0.27	0.93	0.29	0.88
	1,300	0.31	1.13	0.35	1.05	0.42	0.87
Siloseal	300	0.32	0.95	0.20	0.59	0.32	0.68
	750	0.32	0.90	0.32	0.81	0.44	0.86
	1,500	0.45	1.30	0.35	1.08	0.41	0.88
Envelon	350	0.45	0.70	0.44	0.69	0.50	0.52
	700	0.47	0.56	0.46	0.47	0.43	0.55
	1,100	0.52	0.64	0.53	0.62	----	----
Elascote	350	0.55	0.59	0.55	0.75	0.35	0.85
	1,000	0.51	0.74	0.57	0.73	0.45	0.79
Polychloroprene	300	0.88	1.33	----	----	0.34	1.15
	450	----	----	0.45	1.29	----	----
	850	0.73	1.25	0.30	1.17	0.21	1.24
	1,350	0.73	1.16	----	----	----	----
	1,500	----	----	0.25	1.14	0.20	1.07

The Wastolan acrylic is not included in this table because it shows anomalous behaviour. It was the only one which possessed a yield point, that is there was a critical point beyond which elongation continued with a reduced or reducing tensile strength below the maximum tensile strength of the critical point. The decision as to whether the yield or break point should be used for assessment is clouded by the fact that the yield point gives 50 to 80% higher tensile strength, but the elongation is only 20% of break point elongation. The choice would depend on integrity of the seal. Since we have not measured this, we make no choice as to which is suitable. All previous strength and elongation figures were based on figures for the break point on the assumption that there appears to be an integral film until that point.

Adhesive (Peel) Strength of Films

This is considered as a critical property of a film. The elongation pathways illustrated in Figure 1 indicate that the ability of the sealant to peel from the substrate is an essential property to accommodate excessive structural movement. The adhesive strengths of the films to new and old galvanised sheet steel is presented in Table 2, along with the tensile strengths for a 700 micron film. The figures in brackets beside the tensile strengths are the tensile strengths converted to a linear force (kgf/cm) for comparison to the peel strength.

There is one feature of the results which should be noted; the films gave an initial peak strength which was slightly higher than the residual peel strength. Gaseal was the only film with a significantly larger initial peel strength.

The observation was that only the Envelon and Elascote peeled from the surface in an unreinforced state. This is consistent with the data in the table. Figures with an asterisk indicate cohesive peeling rather than adhesive peeling.

SPECIFICATION DESIGN

The principles established earlier are quite clear. Good elongation and the ability to peel from the substrate are the important characteristics. The PVC coatings on their own will peel, but they have lower percentage elongations. They need a surface coating to give protection from UV radiation. Acrylic coatings, if used alone, need reinforcement, which increases labour costs at application. Combination of the two systems is possible, and can take two extremes:

I. Thick PVC and thin acrylic, to give protection from UV radiation.

II. Thin PVC and thick acrylic. This offers the potential for acrylic peel with reinforcement. The combination gives maximum elongation characteristics and has relatively inexpensive application costs.

Table 2 – Adhesive (Peel) strength of films

	Peel Strength at 25°C kgf/cm^2		Tensile Strength at 25°C 700 m kgf/cm^2 (kgf/cm)
	OLD	NEW	
Wastolan P	1.61	0.14	3.0 (0.2)
Wastolan	3.13	2.81	7.5 (0.5)
Flexacryl	*2.00	*2.44	17.5 (1.2)
Siloseal	*1.64	*0.85	19.5 (1.4)
Gaseal	*1.12	1.16	24.0 (1.6)
Envelon	0.89	1.05	32.0 (2.2)
Elascote	*1.10	1.20	46.0 (3.2)

* Failed cohesively

Table 3 Tensile Strength and Elongation of foams at 25°C

FOAM	TENSILE STRENGTH	% ELONGATION
Formafill	0.94 kgf/cm^2	approx 10%
Aerofroth	1.56 kgf/cm^2	approx 20%
ICI Rigid	3.39 kgf/cm^2	approx 6%
ICI Flexible 1	1.00 kgf/cm^2	90%
ICI Flexible 2	0.46 kgf/cm^2	140%

We believe, that with proper consideration of the physical properties of the films, any combination of the acrylic and PVC films in Table 2 will be able to seal grain storage silos satisfactorily. To illustrate how to select materials to meet a particular specification from data derived from this study:

It is essential that the tensile strength of the film must be greater than the peel strength, and that the PVC film should be weaker than the acrylic film. Consider a proposed combination of a 100 micron film of Envelon and a

500 micron film of Gaseal. Figure 7 gives details of tensile strength for varying thicknesses of film. Extrapolating the data for Envelon, a 100 micron film is shown to have a tensile strength of 47 kgf per cm^2 yielding a strength of 0.47 kgf per 1 cm wide strip. A 500 micron Gaseal film has a strength of 28 kgf per cm^2 yielding a strength of 1.35 kfg for a 1 cm wide strip. It is therefore three times as strong as the Envelon film.

From Table 2, a 700 micron film of Gaseal is shown to have a linear resistance equal to a force of 1.6 kgf per cm; a 500 micron film will be expected to have a value of 1.2 kgf per cm. The adhesive or peel strength of Envelon is of the order of 0.9 to 1 kgf per cm.

On this basis, the combination of Envelon at 100 micron dried film thickness (DFT) and Gaseal at 500 microns DFT would be satisfactory.

FOAM SEALANTS

The same consideration of physical properties can be applied to the foam sealants. They are not structural materials that can be expected to resist the forces applied by a silo when it is being loaded. Therefore, the ability to yield is a critical property.

The forces applied can be tensile, shear or compressive. In Table 3, the tensile strength and percentage elongation of five commercial foams are presented. Three are rigid foams, while two are flexible. The rigid foams do not actually elongate under stress. They begin breaking immediately a stress is applied.

In adhesive or peel strength tests on the foams, a force was applied in a shear mode at 90° to the adhesive bond. Four foams steadily sheared from the surface failing cohesively, while the fifth failed suddenly over the entire surface area of the bond. Foams which will partially fail resemble our peel under stress philosophy for films and would be technically preferred.

We believe that the flexible foams are the most appropriate for sealing as they will yield under strain and the elongation is easily accommodated by the sealant membrane applied to the surface of the foam. A rigid foam which snaps can be expected to cause immediate breakdown of that sealant membrane.

CONCLUSION

We believe that the ability of sealants to give under load is critical. The study of film and foam properties presented here has enabled us to develop a way to maximise this characteristic by proper specification design.

FIG. 2 ELONGATION VS THICKNESS at 0°C

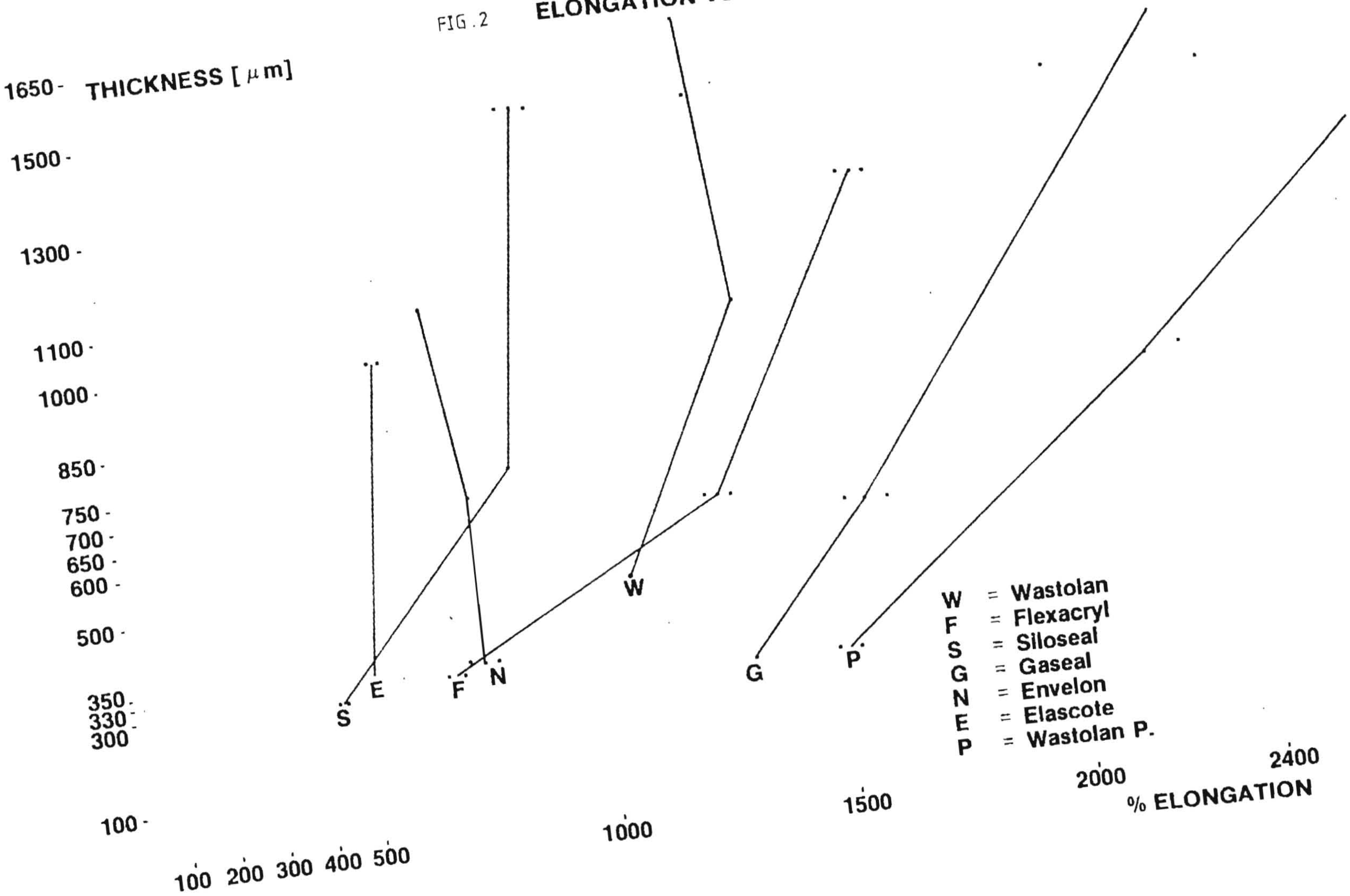


FIG. 3. ELONGATION VS THICKNESS at 25°C

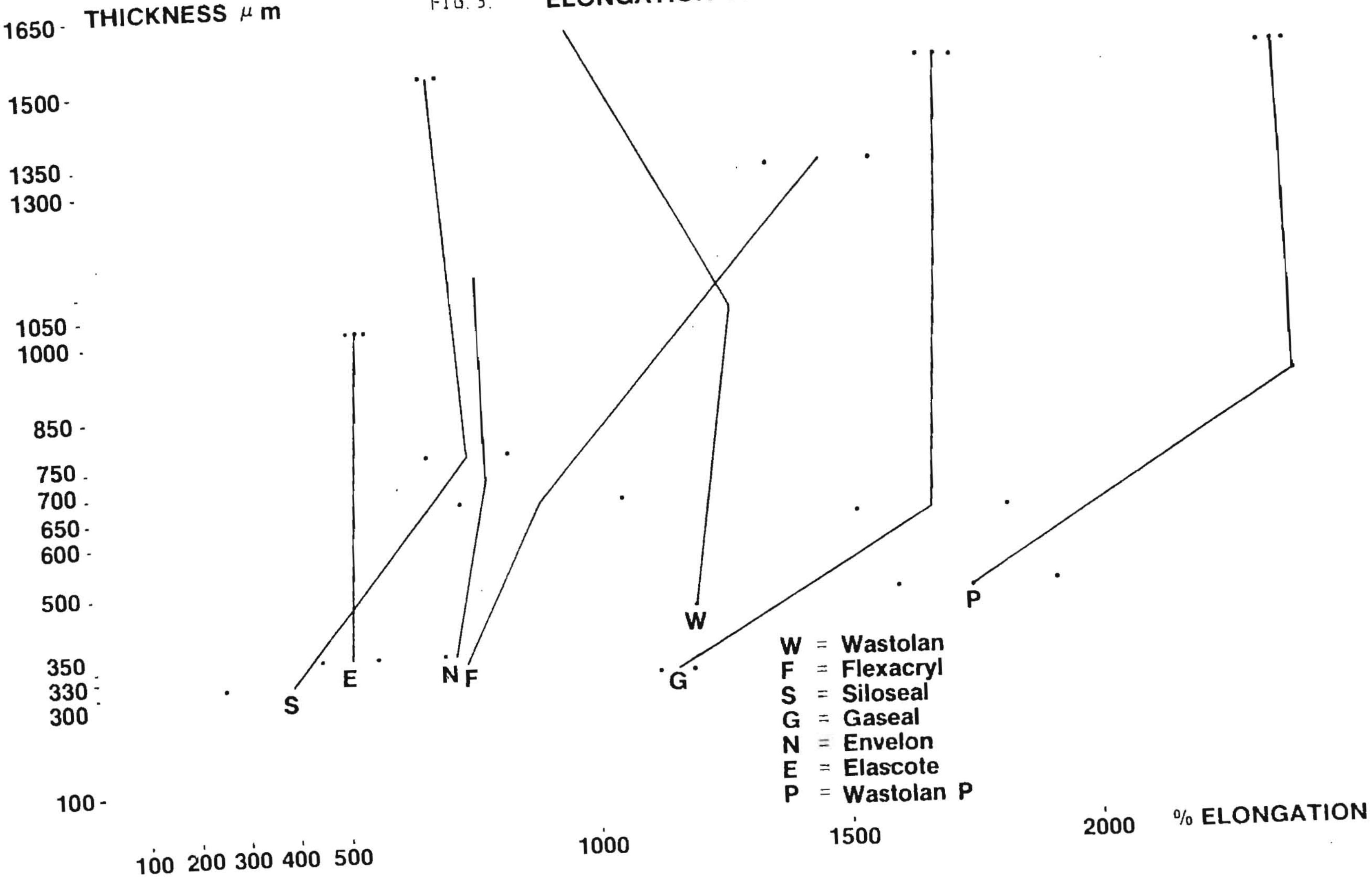


FIG. 4. ELONGATION VS THICKNESS at 50°C

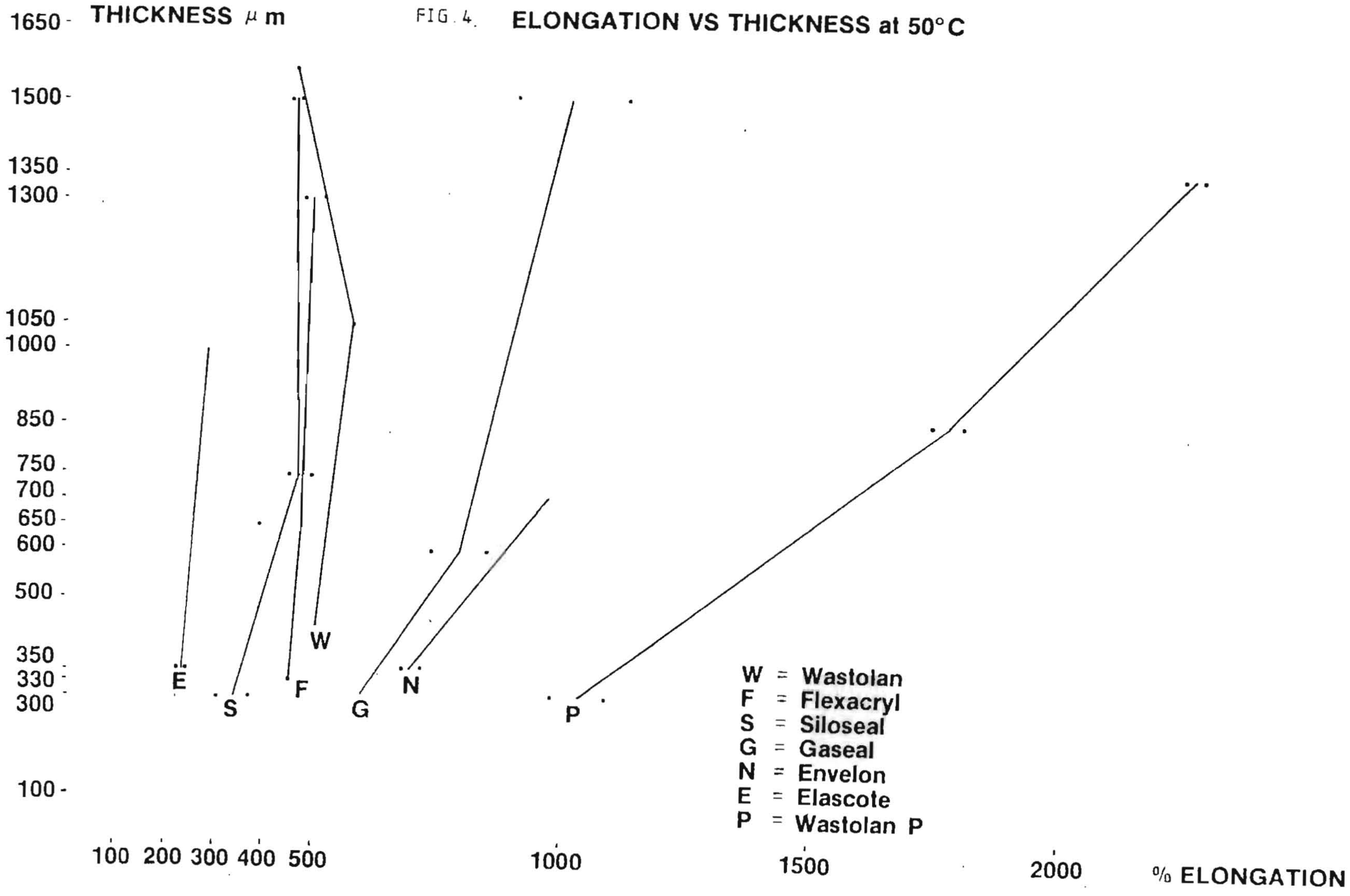
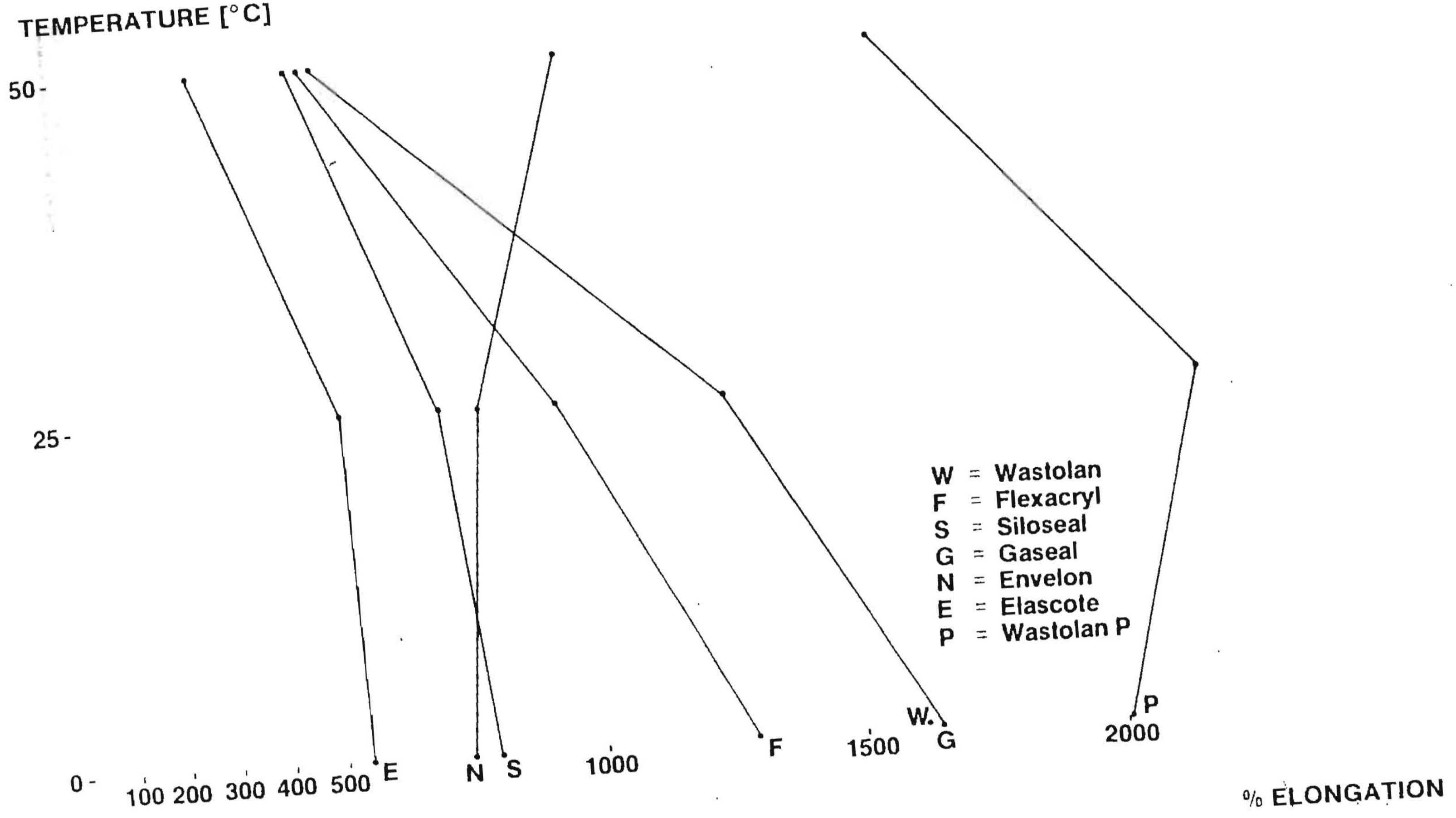


FIG.5. **ELONGATION VS TEMPERATURE at 700 microns D.F.T.**



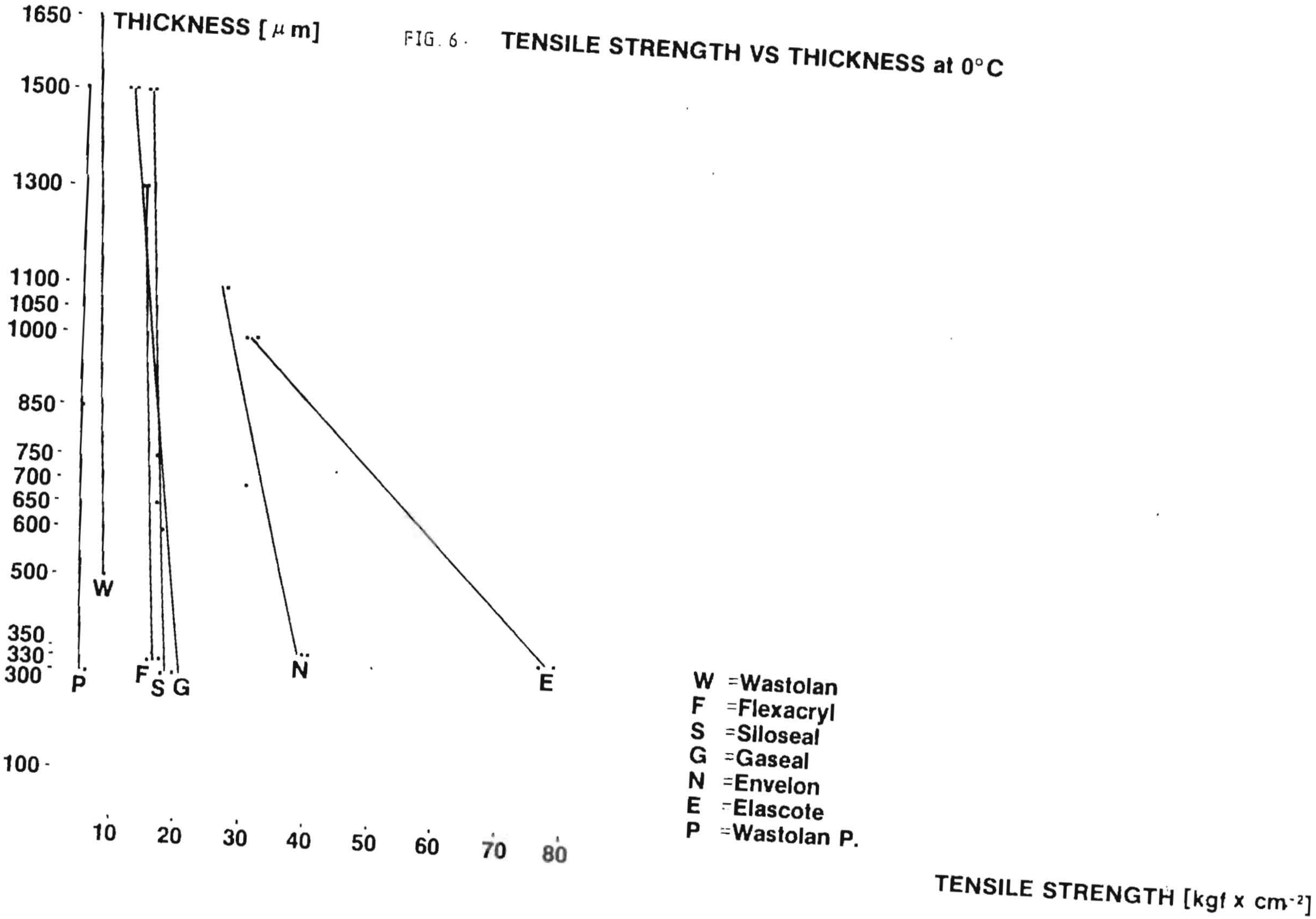


FIG. 6 · TENSILE STRENGTH VS THICKNESS at 0°C

FIG. 7. TENSILE STRENGTH VS THICKNESS at 25°C

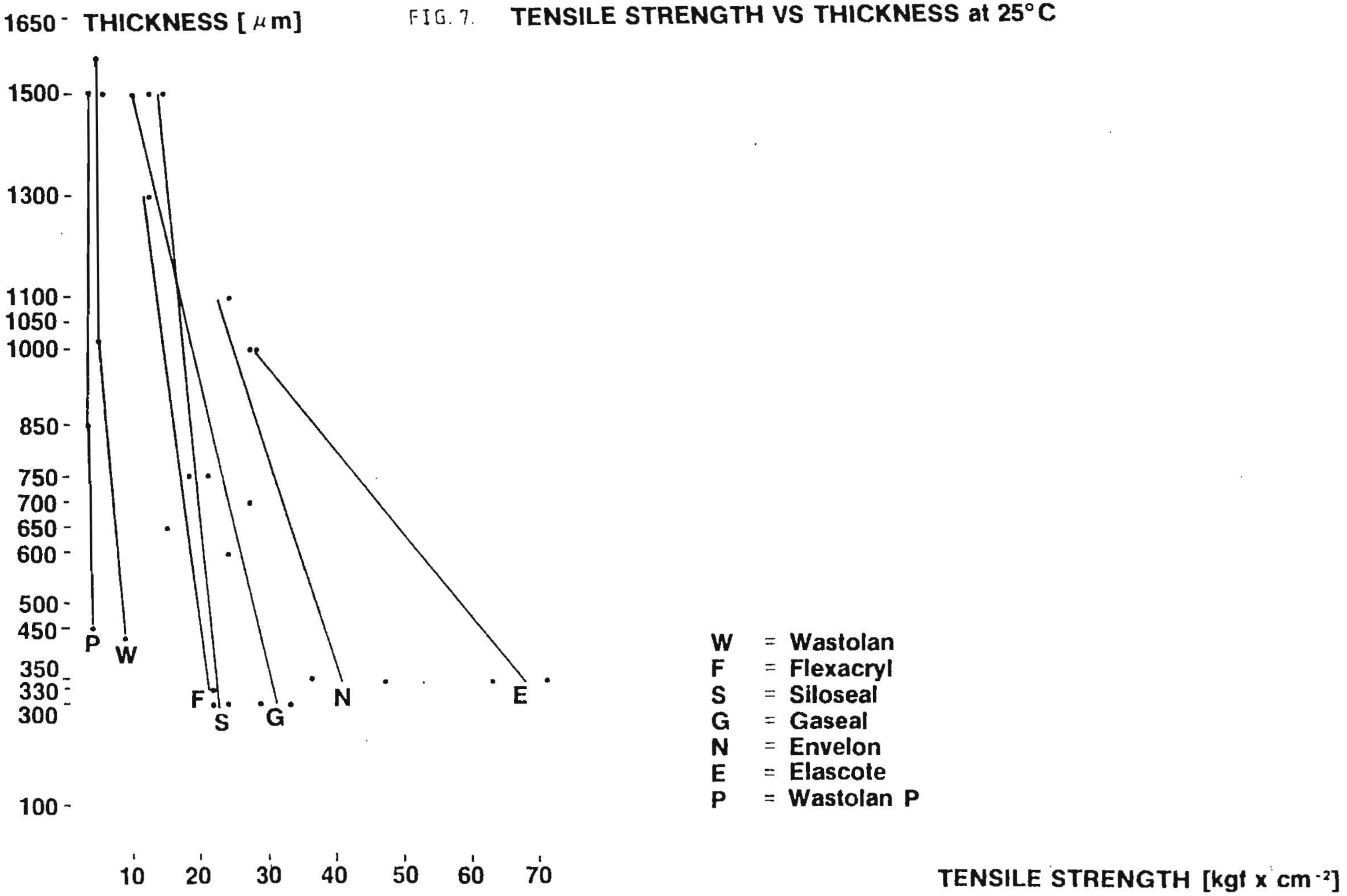


FIG.8. TENSILE STRENGTH VS THICKNESS at 50°C

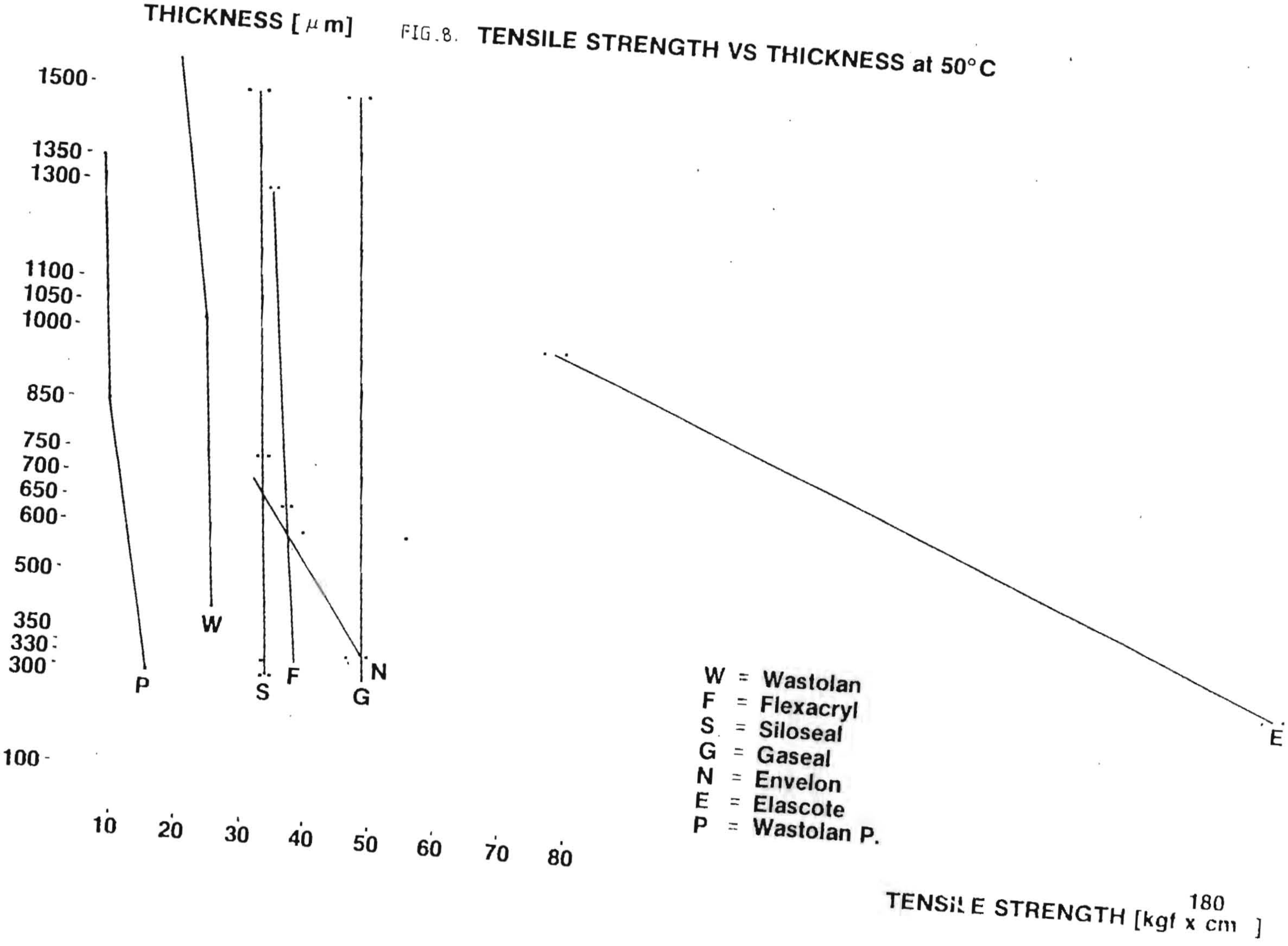


FIG. 9. **TENSILE STRENGTH VS TEMPERATURE**
at 700 microns D.F.T.