THE PROPERTIES OF POLYMERIC FILMS AND THEIR INFLUENCE ON THE DIMENSIONAL STABILITY OF WOVEN PILE CONSTRUCTIONS

THESIS

submitted

by

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SUMMARY

Though it was realised that size pastes did not form true film layers on the back of the carpet, yet it was thought that evaluation of film characteristics might throw some light on the actual behaviour of protective coatings in carpet backing. For this reason, physical properties of films of various sizing mixes have been investigated. Thin films suitable for mechanical testing were obtained by evaporation of size pastes on "Perspex" trays. The methods used included the determination of tensile strength, extensibility, bending length, flexural rigidity and flexing strength of size films.

In order to study the relationship between above characteristics of free films of sizing mixes and characteristics of size films when applied to carpets, various Spool Axminster structures were back-sized on a small scale back-sizing unit. The latter was especially designed and constructed in the Department to meet the requirements of the present work.

The properties of the carpets investigated, as a measure of efficiency of back-sizing agents, included determination of tuft withdrawal force and stiffness

characteristics in the unfinished and sized states. Determinations of these characteristics were also extended for sized worn carpets. For wear treatment of sized carpet samples "Bocking Tetrapod" machine was employed. This was necessary because it was realised that true value of any sizing mix could not be evaluated until its resistance to wear was known.

The property of increase in tuft withdrawal force with any particular mix after wear has been shown to have some bearing on both the tensile and flexing strength of free size films of that mix. In this respect, a new method of approach has been suggested. However, no relation has been found between stiffness characteristics of various sized carpets and those of free size films.

In addition, viscosity characteristics of various sizing mixes have been studied under varied shear rate conditions and temperatures. For this purpose, "Ferranti Portable Viscometer" was employed. It has been shown that viscosity of the size mix changes with variation in shear rate conditions and temperatures. It has, therefore, been suggested that for process control, viscometer should be capable of providing reliable readings under varied shear conditions. The variation of viscosity with temperature established the importance of temperature control in the back-sizing process.

GENERAL INTRODUCTION

AND

SURVEY OF LITERATURE

CHAPTER 1.

GENERAL INTRODUCTION

AND

SURVEY OF LITERATURE

PURPOSE OF BACK-SIZING

[illegible] which is ready for sale should be resistant to [illegible] during the course of planning. When a carpet [illegible], it must be flat with no danger of twists or [illegible] bent up corners and other signs of unlevelness. [illegible] be [illegible] before [illegible] Back-sizing is [illegible] by applying to the [illegible] film [illegible] all of [illegible] and [illegible]ted to [illegible] accomplish its [illegible] the process of back- [illegible] purposes:

To bind [illegible] the pile yarns of the carpet [illegible] (i.e. improvement in tuft anchorage)

2) To impart stiffness or rigidity

To increase weight

[illegible] fuzziness or hairiness on the back of [illegible] and

To increase durability.

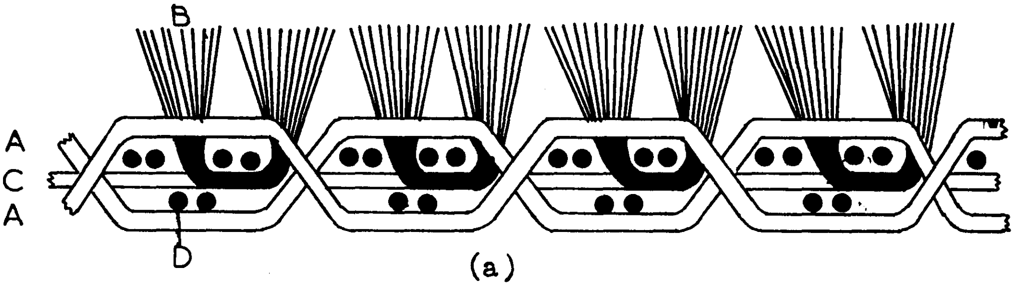
1.1 PURPOSE OF BACK-SIZING

A carpet which is ready for sale should be resistant to distortion during the course of planning.[7] When a carpet is laid, it must be flat with no danger of twists or wrinkles, bent up corners and other signs of unlevelness. To achieve this, carpets require to be stiffened before they can be presented to the public. Back-sizing is the process of stiffening the carpets by applying to the reverse side of structurally complete carpets a film forming adhesive material so spread as to cover all of the parts exposed to the back evenly and regulated to penetrate towards the face enough to accomplish its purpose and no more. In addition, the process of back-sizing should serve the following purposes:

1) To bind the yarns, especially the pile yarns of the carpet to the ground structure (i.e. improvement in tuft anchorage)
2) To impart stiffness or rigidity
3) To increase weight
4) To dress down fuzziness or hairiness on the back of the carpet, and
5) To increase durability.

1.2 CARPET CONSTRUCTIONS

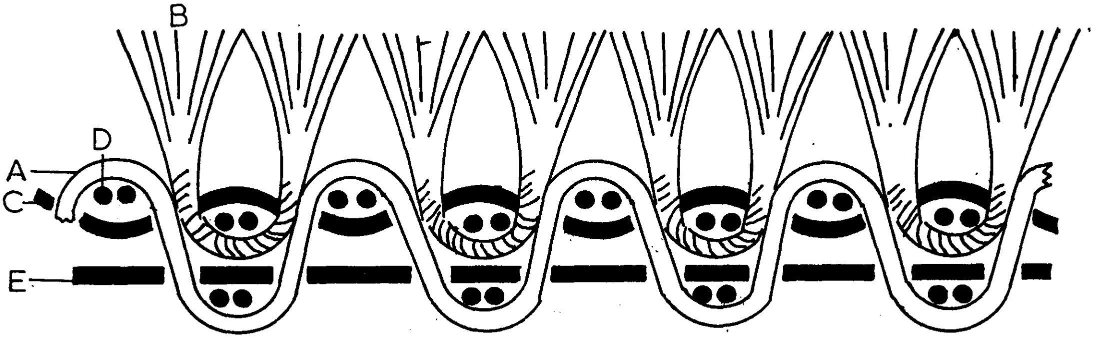
The amount of stiffening required varies with the type of the carpet. For example, some Wiltons containing near to the maximum number of ends and picks have so much strength and body that they will withstand careless handling and still preserve shape[1]. On the other hand, in the popular 3-shot Platt Spool Axminster weave, the points where the chain ends cross produce an effect of a hinge, the carpet is easily bent round the crossing point between the repeats of the 3-shots, therefore, these types of carpets require maximum amount of stiffening. To apply the work in detail to the various Axminster and Wilton carpet structures would obviously take a considerable time. Hence it was decided to confine the present work to spool Axminster structures only. The spool Axminster carpets are popular on account of their large range of colour and their comparative cheapness. In the narrower widths there are various weaves employed, but the broad loom is built to make 3-shot structure either as shown in Fig. 1 (a) or as shown in Fig. 1 (b). These structures give a type of back which is open to receive the full benefit of back-sizing in the finishing stages.



(a)

A - Chain Warp. B - Tufts. C - Stuffer Warp.

D - Double Weft.



(b)

A - Chain Warp. B - Tufts. C - Tuft Support Warp.

D - Double Weft. E - "Float" or Stuffer Warp.

FIG. 1. SPOOL AXMINSTER STRUCTURE

(a) 3 - Shot Weave for Platt Loom.

(b) The Crompton 3 - Shot Weave.

Generally, structure (Fig. 1a) is associated with the split shot Blatt system, whilst structure (Fig. 1b) is produced on the Crompton loom. Samples of both constructions were used in this investigation.

1.3 SIZING MATERIALS

Up to about the middle of 1930's, most of the sizes were based on materials found in nature or prepared from them, such as starch and its dextrine derivatives. Since then the tremendous growth of the plastics industry has seen increasing proportions of carpeting being backsized with synthetic rubbers and resins each year. At the present about one-sixth of all the square yardage produced in this country, or about ten million square yards, are backsized with this class of materials.

Briefly the materials employed for carpet backsizing may be grouped under the following four broad headings:-

1) Native starches
2) Modified starches
3) Synthetic resins
4) Rubber latices

1.31 - Native Starches

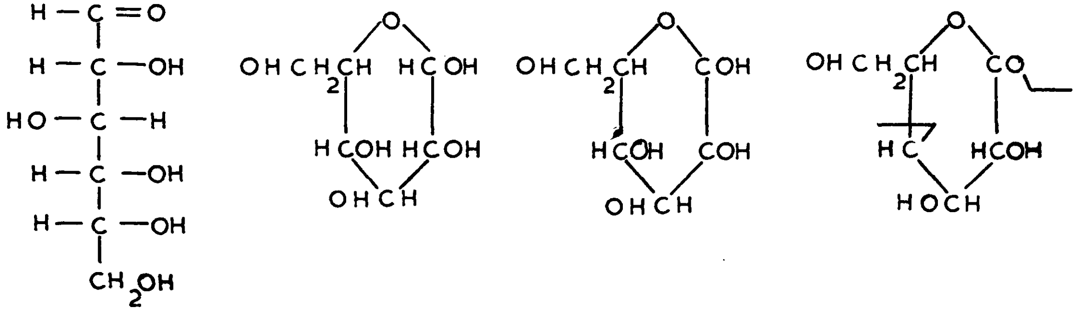
For textile use, natural starches are derived mainly from potatoes, wheat and maize, and as a matter of interest, the starch contents of these various vegetable materials are approximately 18 - 20 per cent. for potato, 54 - 58 per cent. for wheat, and 55 - 65 per cent. for maize.

Starch in dry form appears in groups of molecules insoluble in cold water, but when heated these groups first swell, then rupture and form a paste. The body or consistency of the paste varies from one type of starch to another, but the type of paste is characteristic of the type of starch, and the various qualities are therefore easily identifiable. There is also a considerable difference in the particle size from one type of starch to another, but the size of the individual particle is characteristic of the plant from which the natural starch was derived, and thus another means of easy identification exists.

Of the commercially available natural starches for textile use, potato starch has many attractive properties which make it extremely suitable for many types of processing, but in its unmodified form, these advantages are minimised by other very considerable disadvantages, chief among them being the phenomenon of retrogradation. The working of this phenomenon is described by Clark.[2] It is necessary to consider the constitution of starch, briefly, before the phenomenon of retrogradation and crystallisation is understood.

Most of the common starches contain two polysaccharide components - a long linear chain of polymerised glucose units, and a highly branched or tree-like glucose polymer. Thus:-

(a) Starch molecule is built up of D (+) glucose units (Fig. 2a)



(a) D (+) Glucose

(b) D (+) Glucopyranose

(c) ∝ - D (+) Glucopyranose

(d) ∝ - D (+) Glucopyranose residue

Figure 2.

(b) these units exist in the pyranose ring (Fig.2b)

(c) the pyranose ring is in the α-form (Fig.2c), and

(d) the α-form of these glucopyranose rings are bonded together through oxygen atoms in the 1, 4 positions (Fig.2d).

Thus when the units in Fig.2d are bonded together, a thread like molecule of the type shown in Fig. 3 is obtained.

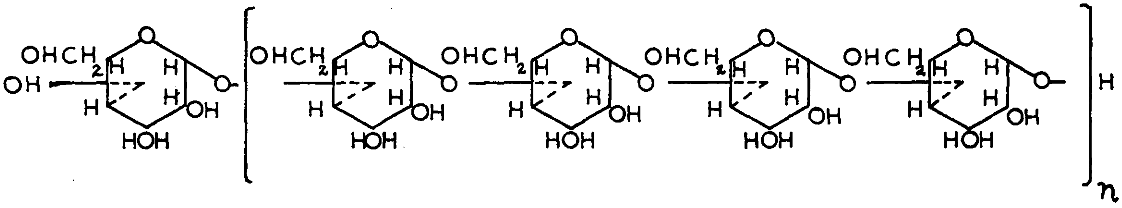
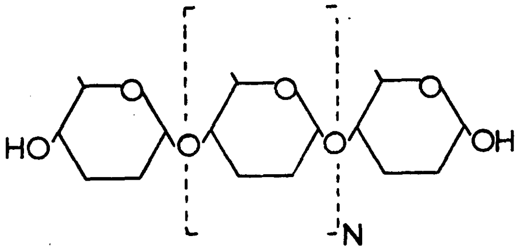


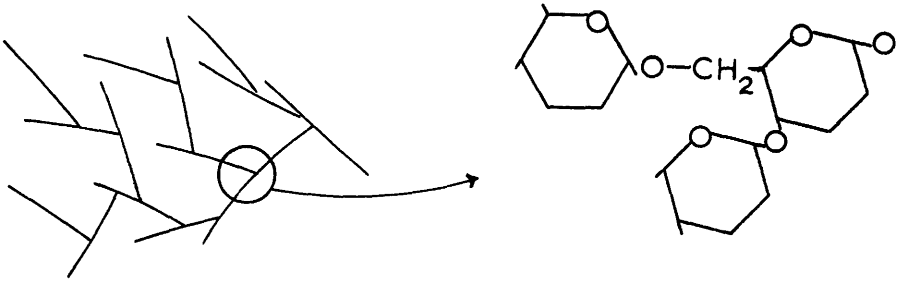
Figure 3

Thread-like molecule obtained from α- D (+) Glucopyranose residues

A long linear component is called Amylose and the branched one is known as Amylopectin. Their molecular chains are shown in Fig. 4. It would not be far out if the proportions were stated at a general average of 25 per cent. Amylose, 75 per cent. Amylopectin.



LINEAR FRACTION (N = 400 - 1000)



BRANCHED FRACTION

Fig. 4. Structure of the linear and branched starch fractions.

A solution of potato starch is ideal for observing the phenomenon of retrogradation, as after preparation by boiling, the solution is very transparent, whereas comparable solutions of cereal starches (maize and wheat) are very cloudy under similar circumstances.

To observe the phenomenon of retrogradation, therefore, a solution or dispersion of potato starch in water should be prepared by boiling, and the solution should be allowed to stand. As it cools a steadily increasing cloudiness will be observed in the once transparent solution, and on further cooling a separation of water occurs. At this stage part of the starch commences to precipitate as an insoluble solid. The insoluble solid is the Amylose content of the starch, which on cooling, commences to crystallise, and the commencement of crystallisation is shown by the commencement of cloudiness of the solution. On further cooling more and more of the total starch which was formerly in solution precipitates, and finally practically all the potato starch which was initially in solution will be observed as a precipitate at the bottom of the container. If the mixture of precipitated potato starch in water be raised to the boil once again, it will be noted that the precipitate cannot be completely redissolved to a gel, so that retrogradation is therefore not reversible, and the change that has taken place in the natural starch is permanent.

The phenomenon of retrogradation is of considerable technical importance to all natural starch using industries, as the disadvantage is common to all natural starches and is the basic reason why they give less satisfactory results in textile processing than the ideal.

In addition to the phenomenon of retrogradation, natural starches exhibit high degree of crystallisation on drying out. The question of crystallisation on drying is of particular importance in carpet work. The greater the degree, the harsher will the handle be and the more readily will the starch dust out; the action of walking greatly aggravating the latter. The demand from carpet manufacturers is for a finish which will give a more "leathery handle" and which will not break up and dust out.

In order to follow the phenomenon of crystallisation on drying, it is again important to remember that natural starch is composed of two components Amylose and Amylopectin.

Amylopectin has a branched structure and because of this it forms molecular aggregates in solution only with difficulty so that it remains in solution or colloidal dispersion. Amylose, on the other hand, is unbranched, the molecular chains can therefore approach quite closely in solution, leading ultimately to precipitation and on drying to crystallisation.

This effect is fully manifested in native starch film. When dried on a textile material, the film is brittle, inelastic, harsh and the material is badly penetrated and irregularly covered.

Hager[3] has summarised the shortcomings of natural starches, which have been used in the back-sizing process for a considerable period, as follows:-

a) they complicate cleaning or scrubbing with water,

b) are excellent food-stuffs for mildew, decay organisms and insects,

c) vary widely in stiffness and extensibility with changes in relative humidity, and

d) cannot be compounded to give the high degree of elasticity required in heavy backings.

The field was therefore wide open for the production of modified starches, and at the close of the last century British gum and dextrines were commercially available, and the forerunners of the cold soluble starches appeared in the early 1900's.

1.32 - Modified Starches

Definition: The term "modified starches" has been defined by Degering[4] as compounds or mixtures which retain intact starch molecule to an appreciable extent.

The more important of these, according to studies to date, are the acyl, nitro, and alkyl derivatives. These are also referred to in the literature as starch alkanoates, as starch nitrates, and as starch ethers.

Whereas the definition in the preceding paragraph implies that the starch molecule tends to remain intact in the preparation of these various derivatives, it must be conceded that this is only qualitatively true. With the techniques employed in the synthesis of derivatives of starch, there is little doubt that some degradation of starch molecule occurs.

Among the modified starches may be mentioned the following groups in which interest has been shown in the past and in recent times for sizing and finishing of textiles.

(1) Thin boiling starch and dextrine.
(2) Swelling starches.
(3) Starch ethers and esters, and
(4) Chlorinated starches.

1.321 - Thin Boiling Starch and Dextrine

It has already been shown that natural starches cannot be used in all instances, because of the varying requirements for different applications. For this reason the starch industry developed products with a consistent degree of degradation. With these so called "thin boiling" starches, which are also referred to as "soluble" starches, the average size of the molecule has been reduced by chemical treatment. This is frequently brought about by the action of oxidising agents, although in some cases enzymes or strong inorganic acids are used. Degradation by means of oxidation offers the advantage that the products gelatinise less quickly, while fewer reducing groups are formed than with other degradation processes. There is a direct relation between degree of degradation and the viscosity of a thin boiling starch. Products with the highest degree of degradation give the lowest viscosity.

The development of a variety of products with different degrees of degradation makes it possible to choose the product most suitable for any purpose. This[5] is illustrated by the following survey of the thin-boiling starch products of W.A. Scholten's Chemische Fabrieken, N.V., mentioned in the order of their degree of degradation. For all products the viscosity of 10% solutions at 70°C. (160°F.) was measured, using the Höppler viscometer. For comparison the viscosity of a 10% solution of potato starch is included.

TABLE I.

Product	Viscosity of a 10% solution at 70°C (160°F) in centipoises
Potato starch	2,070
Textiline Supra	657
Textiline W	185
Textiline S	118
Textiline W_1	104
T - Gum	22
Superdex	10

In comparing the properties of these thin-boiling starch products with the properties of potato starch, the following conclusions have been made:

(a) The viscosity progressively decreases, which is apparent with Textiline Supra and Textiline W. While Textiline S and Textiline W_1 give solutions which are considerably thinner, solutions of T-Gum and Superdex are almost as thin as water.

(b) A slight degradation of the starch increases the binding power, presumably because there is an improved contact between the molecules in the dried film.

(c) Penetration into yarn or fabric increases with the degree of degradation.

(d) The stiffening action decreases with the degree of degradation of the product. A 10% solution of Textiline W_1, for this reason, gives a much softer finish than a 10% solution of Textiline Supra.

(e) The full feel obtained with thin-boiling starch is related both to the quantity of starch taken up by the fabric and to the penetration. To obtain a very full feel, high absorption and good penetration are required, so that with a high concentration of Superdex the fullest feel can be obtained.

In the carpet trade, where the backs have to be hard and yet pliable, Superdex produces better and cheaper results than the animal glue used formerly.[6]

In the case of dextrines the degradation takes place by means of dry heating, in some but not all cases in the presence of chemicals (as a rule acids or acid splitting substances). By variations in the quantity of acid, the time of heating, the raw material and the temperature, various types of dextrines can be obtained. The following are the typical groups:

(1) White dextrines,
(2) Yellow dextrines,
and (3) British Gums.

As dextrines, generally speaking, are strongly degraded products, they are not widely used in carpet back-sizing. Furthermore, with dextrines, harshness and dusting out occur, because, by their nature, solutions of very high concentrations are necessary to produce required stiffness. The nature of the material then leads to harshness on drying out and the high concentrations used produce more solids than the structure of the carpet can conveniently hold.

1.322 - Swelling Starches.

By swelling starches are meant starch products which have been treated in such a way as to make starch soluble and capable of swelling in cold water. To effect this the starch, which has been diluted or pregelatinised with a little water, is spread on a heated surface.

At a high temperature and under high pressure it is pressed to form a thin layer and dried at the same time. The starch film thus obtained is scraped off and ground. After this treatment the granular structure of the starch has disappeared. By the addition of certain chemicals an agglomeration of amylose and amylopectin is brought about. As a result the solution has an improved stability, i.e. it will not gelatinise. It is true, however, that on drying retrogradation may occur.

The cold swelling potato starches, such as Quellin and its sister products, represented a very considerable advance in natural starch treatment, but they were by no means perfect, and although crystallisation was retarded, it was not entirely eliminated, and if the products were allowed to cool down after preparation, they lost some of their thickening power.

1.323 - Starch Ethers and Esters

The first recorded interest in the ethers of starch is disclosed in a patent, which was issued in 1912.[7] As has already been mentioned, the unfavourable property of starch is the tendency to crystallise. To prevent this crystallisation, the starch molecules should be given side groups, so that the molecules are, as it were, kept apart from each other. It has been found that the best way to link these side groups to the starch is to use the OH-groups, present in the glucose units from which the starch molecules have been built.

These OH-groups can be etherified or esterified. Etherification is preferable, as ethers have a much greater stability than esters. A disadvantage of esters is the fact that they will easily hydrolyse or saponify, meaning that the effect of the groups which were introduced is lost.

In 1920, West[8] published a paper in which he considered the raw materials and the procedure for the production of ethers of starch. He characterised some of the ethers he obtained. In the same year Bayer[9] obtained a patent for the manufacture of the hydroxy ethers by the reaction of alkene oxides on starch.

Dreyfus[10] also obtained a patent for the production of hydroxy ethers of starch by use of such reagents as ethylene chloride, ethylene chlorohydrin, epichlorohydrin, and similar chemicals in the presence of appropriate condensing agents.

Maksorov and Andrianov,[11] in 1934, reported on the benzyl ethers of different starches and compared the properties of these derivatives.

Several other workers have worked on the production of starch ethers, since then, but a complete account of their work is beyond the scope of this thesis.

Between 1920 and the beginning of war in 1939, the modified products of starch were extensively used, and in 1945, W.A. Scholten's Chemische Fabrieken N.V., of the Netherlands, took out patents for an entirely new range of modified starch products, which were marketed under the collective name of "Solvitose", and these products undoubtedly represent the greatest development in starch technology in this present century.

The textile qualities of these products have been evaluated in the present investigation in relation to their application as the back-sizing agents for carpets.

The Solvitoses are etherified potato starches and their advantages over native starches in sizing have been mentioned by several investigators.[2,6,12,13]

1.324 - Chlorinated Starches

Chlorination of raw starch or pretreated starch is employed to produce fluid starches. Reaction is carried out in an autoclave with an excess of chlorine at a temperature of 70°C. for eight or more hours depending upon the degree of modification desired. Solutions of chlorinated starches are of low viscosity and they have good film characteristics.

1.33 - Synthetic Resins

Although starch-type materials have always been the first choice for any back-sizing mix, it would not be logical and desirable to neglect new suitable materials. The most important alternatives, in this respect, are rubber latices and synthetic resin emulsions. The investigation of these products has paralleled the investigation of the modified starches, in that, with each, the aim has been to devise materials which would be easy and cheap to use and which would give the stability, flexibility and permanence which finishes from older materials usually lacked.

Synthetic resins, particularly the poly-vinyl acetate emulsions, find some use in back-sizing work in conjunction with starch derivatives; these give a mix of suitable concentration and viscosity which can be handled by the size roller.

P.V.A. preparations often replace part of the starch and glue content of an ordinary formulation and whilst it is claimed that they improve the finish,[14] they introduce the disadvantages of higher costs and of reduced speeds of processing.

Finally, any desire to develop polyvinyl acetate as a unit size will require producing it in other than emulsion form, unless emulsions can be made such that they will be of suitable viscosity when diluted to back-sizing concentration.

1.34 - Rubber Latex

Rubber latices do not find widespread application because of the price structure of carpet production. They are mainly used for special purposes such as tufted carpets, for which they are particularly suited and for needle loom carpeting. In conventional carpets they are nowadays employed mainly for very low quality goods, where good tuft anchorage cannot be obtained in other ways.

1.4 SIZING METHODS

Under this heading three major stages involved will be considered. They are:-

(1) Size preparation

(2) Size application

and (3) Drying of sized material.

1.41 - Size Preparation

Mixing equipment nowadays employs fast mechanical stirrers. It is well enough known that continuous high speed stirring will gradually reduce the viscosity of a starch mix. Therefore, continuous high speed stirring may be employed only while the mix is being prepared and stirring should be used sparingly afterwards. Of the slower speed stirrers, the most successful is the type which has concentric counter-rotating cages mounted one within the other. The shearing effect of the blades is often criticised, but starch breakdown is confined in practice to native, or only slightly modified starches. There has been no reported occurrence with the thin-boiling starches normally used, and the starch ethers seem to be immune. The latter is not unexpected, since these products are completely soluble in water, and the shearing takes place on the less soluble fractions of more normal starches.

As regards boiling, open steam coils are favoured in industry because with closed coils, and even more with steam jacket systems, it is almost impossible to bring a mix to a full boil unless conditions are very favourable. It is very essential to do this with every starch or starch derivative having any adhesive power, if regularity in the mix is required. The only exception to this are the newer materials, like the starch ethers.

Crone,[15] by plotting viscosity-temperature curves for some of the native and thin-boiling starches, has shown why it is necessary to boil a mix until it reaches its final viscosity, and why one should not be tempted to run the mix to the trough immediately it reaches its maximum viscosity and looks very thick and tacky. In fact, it has been shown that maximum viscosity is attained well below the boil. It is not enough to prepare a mix carefully and then allow it to flow to the size trough, no matter what temperature it may happen to have reached while standing. The importance of temperature control in relation to regularity of finish has been well established. This is important, because the amount of mix lifted by the roller is closely governed by the viscosity of the mix, which, in turn is directly related to its temperature; the roller will pick up more size liquor as the temperature falls, i.e. as the viscosity increases. A thicker mix may give, not only a heavier finish, but also a finish which will be crisp and will dust off more readily, because the rate of penetration of size into the backing is slower when its viscosity is high.

Of the many size cooking systems available,

mention may be made of the Norcross Sizeometers[16] for which the following advantages have been claimed:
(a) saves labour; (b) cuts operating costs;
(c) reduces waste; (d) simplifies job; (e) improves quality; (f) increases production.
The sizeometer cooks the size under pressure and mechanically breaks it down as it is drawn from the bottom of the kettle by a large centrifugal pump and returned to the kettle through an internal cooker.
The Norcross viscometer is used to record and control the viscosity of the size.

1.42 - Size Application.

In all cases the carpet, in a length, is passed continuously with its reverse side in contact with the upper part of the periphery of the furnishing roller, the lower part of the periphery of which runs in a size bath. Four kinds of furnishing rollers are in commercial use. These are:-

(i) idling, flannel-covered roller;
(ii) driven, flannel-covered roller;
(iii) uncovered roller, driven in the direction of cloth travel;
(iv) uncovered roller, driven counter to the direction of cloth travel.

1.421 - Flannel Covered Rollers

Flannel covered rollers differ fundamentally from uncovered rollers in that, in the former, the carpet picks up size from the roller, while in the latter, the roller transfers size to the carpet. Better penetration of size and regularity of finish are possible with the latter system. Furthermore, flannel covered rollers themselves pick up size to varying degrees depending upon the quality and condition of the flannel. The amount of size which the carpet then picks is liable to vary. With a positive drive a more regular lift of size can be obtained and conditions generally can be controlled better, especially the ratio of cloth speed to roller speed.

1.422 - Uncovered Rollers

This system has two principal advantages. The first is that the roller can be driven appreciably faster than the machine, transferring an excess amount of size to the region of contact between carpet and roller and thus ensuring sufficient liquor is presented to account for any variations in receptivity in backing. The second advantage is that irregular sizing is less liable to occur than with covered rollers, because the surface condition of the roller does not alter.

The advantages of driving a roller counter to the direction of cloth travel are similar to those mentioned above, but even greater regularity of finish is possible. This occurs because a "smearing" action of the roller takes place towards the unsized region of the carpet.

Some systems, in addition to a roller and a doctor blade, also employ brushes which are said to assist in improving the regularity of distribution of the paste.

1.423 - Control of Size Pick-up.

The peripheral speed of the furnishing roller and the linear speed of the carpet are usually not equal and by increasing or decreasing the difference in these speeds, any alteration, due to other factors, in the rate of take up of size by the carpet can be compensated for. The rate of take up can also be controlled by altering the extent of the arc of contact between carpet and roller, or by varying the concentration of size in the bath. The concentration should preferably, however, remain substantially constant as undue penetration of size may occur if the concentration falls below a certain level. In most of the cases, the control of the rate of take up has been affected by the machine operator who made the necessary adjustments according to his judgment.

Jones,[17] recently patented a process for carrying out the back-filling of a continuous length of carpet in which the rate of application of size can be continuously and automatically controlled. The apparatus designed by him is fully described in the patent.

1.43 - Drying of Sized Material

The drying equipment can be conveniently divided into four categories:
(1) Cylinder driers; (2) Chamber driers; (3 Combined cylinder and chamber systems; (4) Infra-red driers.

1.431 - Cylinder Driers

These machines usually have one or two steam heated cylinders up to 8 or 10 feet in diameter, although multi-cylinder machines do exist. Cylinder drying has several advantages for carpet work, notably, that evaporation takes place upwards through the surface and so gives an excellent pile burst.

However, without major modification cylinder driers are unable to give the high production speeds for which many carpet manufacturers call today. Cylinder drying, by its nature, cannot be rapid. There is a limit to the pressure, and therefore to the temperature, at which the cylinders can work, and, unlike chamber driers where large volumes of heated air sweep away the moisture, they depend entirely on "thermal impetus" given to the water molecules by contact with drum. The most successful modification in the recent years has been the introduction of semi-vacuum hoods over the cylinder to improve the drying speed.

Walter[18] has noted that there are three stages in textile drying. Surface water is first evaporated, then more slowly evaporation proceeds from the inner portions of the fabric and, finally, water from the fibre interstices is driven out by more vigorous drying. The same author has also outlined the theory of film formation inside and outside the heating surface of a drying cylinder. It is shown that when a continuous sheet of wet material is brought into contact with the heated surface, there is a considerable temperature drop from the steam space through films, cylinder walls and fabric to atmosphere. The rate of heat transfer can be increased by removing most of the stagnant condensate film.

1.432 - Chamber Driers

Chamber driers are capable of high drying speeds, but this is very much influenced by the quality and temperature of the drying air used. Fundamentally, it is necessary to provide enough heat to supply the latent heat of the water present, and enough air to absorb the moisture produced, so that, unless very large volumes of air are used, and unless this air is at fairly high temperature, then drying efficiency will be low. A criticism of chamber driers is that, since there is not the same directional effect in evaporation as in cylinder driers, the tendency to pile bursting is not so pronounced.

1.433 - Combined Cylinder and Chamber Systems

These are less common than either alone, and, where they are found the main drying is done in the chamber. The cylinder portion generally preceeds the chamber, to obtain maximum pile bursting effect by evaporation up through the carpeting when it contains the highest concentration of water.

1.434 - Infra-red Driers

For general sizing purposes, drying by infra-red lamps would prove at the present time much more costly than drying by steam or hot air. On account of this, besides other disadvantages such as the extra space required, this method is only of theoretical interest.

1.5 PROPERTIES OF STARCH SYSTEMS

The user of starch in industry is interested in the properties of three different starch systems:

(1) Behaviour of the granules,
(2) Pastes or solutions, and
(3) Dried size films.

1.51 - Behaviour of the Granules

Some of the properties of starch granule which are important in textile application are:-

(i) Gelatinisation temperature,
(ii) Rate and extent of granule swelling,
and (iii) Rate and extent of granule solubilisation.

The granules when heated in water above the socalled gelatinisation temperature undergo a progressive swelling. The Kofler microscope[19] hot stage provides a very simple means for determining the point at which the granules start to swell when heated in water. Items (ii) and (iii) describe the way in which starch granules swell and dissolve when heated in water suspension to progressively high temperatures.

From various observations Alsberg[20] concludes that starch pastes,unless specially treated to disintegrate the particles, are not true colloidal solutions but are suspension of swollen granules. He also believes that the viscosity of a paste depend in a large part upon the anotomical structure of the swollen granules. He attributes the swelling of the granules to three factors: rigidity, inherent swelling power of the granule substance and the relation of the mass of the swelling substance to the surface area of the granule. This third factor, which is the relation of increase of volume of spheres to the increase in surface area, indicates that large starch granules have greater mass of swelling substance exerting pressure on each unit of granular surface than smaller ones. Therefore, as Alsberg states, of two granules having the same rigidity but different diameters, the larger one will swell more readily, as the temperature is raised, than the smaller one.

Sprockhoff and Parlow[21] in an effort to find comparative value of small and large potato starch granules separated the small from the large and made viscosity measurements on the respective pastes. These authors report that the small granules of potato starch, if care has been maintained in manufacture, show even a higher viscosity than the large granules. But potato starch presents an exceptional behaviour, as Alsberg[20] and Harrison[22] have pointed out. When heated in water, potato starch granules not only swell but gradually fragmentize and disintegrate. There is, therefore, the possibility that the viscosity of the pastes used by Sprockhoff and Parlow was low because the large granules had become disrupted.

Ripperton,[23] on studying the physicochemical properties of three samples of edible-canna and two samples of potato starches, measured the differences in the swelling power of the starch granule and the viscosity of their pastes at various concentrations. He concluded that the swelling power and viscosity of these starches are not directly proportional but that there is a direct relationship between the viscosity and the products of the concentration of the paste and the volume or "swell" of the swollen starch granules.

He found that potato starch swells more and gives a higher viscosity than canna starch.

Furry[24] observed that the size of the swollen starch granules bears a definite relation to the penetrating and coating power of the starch pastes.

Gaver[25] has attempted to explain the phenomenon of the swelling of starch granules. According to him, the granules swell by imbibition of water which, after initiation, probably continues by osmotic phenomenon. The water penetrating to the interior of the granule dissolves some of the starch substance to form a more concentrated solution within the confines of the outer layers of granule. This highly organised exterior layer, having had some of its solubles extracted during manufacture, serves as an osmotic membrane. On the basis of Donnan equilibrium phenomenon, water continues to penetrate to the centre of the granule and the granule swells.

The modes of swelling of various starches have been evaluated over a range of pasting temperatures by Leach et al.[26] They showed that corn and milo starches exhibited a limited two stage swelling, indicative of two sets of bonding forces which relax at different temperatures. In contrast, potato starch showed very rapid and unrestricted swelling at relatively low temperature, indicating weak and uniform bonding. In general, the authors observed that the extent of starch solubilisation during pasting paralleled the swelling pattern. Thus they employed these two techniques to study the architecture within the granule.

1.52 - Pastes or Solutions

Once the starch granule is swollen a paste is formed. Of all the properties of a paste, one property which is most important to the user in textile industry is the viscosity. Successful application of starch to the various processes of sizing, finishing and printing depends on control of the viscosity within the limits required by the equipment used to obtain the desired effect upon yarn or fabric under consideration.

There is a vast amount of literature devoted to the nature and measurement of viscosity scattered through a wide range of publications. On the measurement side, there are many designs of viscometers, some developed for research investigations only, others for industrial laboratories, and just a few, a very few, for process control.

1.521 - Newtonian and Non-Newtonian Fluids

Newtonian fluids - If we consider a fluid to be in motion such that the adjacent planes or layers are moving with different velocities, a shearing action is set up between the layers or planes and a resistance to shear will be established.

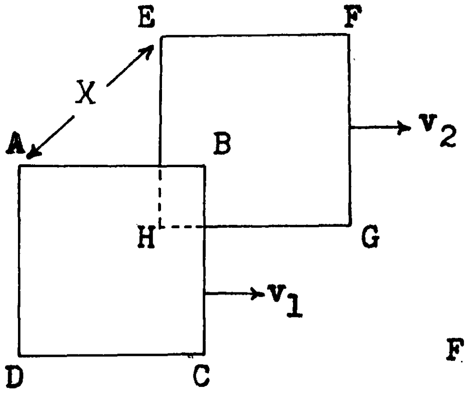


Figure 5

Referring to Fig. (5), ABCD and EFGH are two parallel planes of equal area A, situated distance x apart, in a moving fluid. The velocity at ABCD is v_1 and at EFGH, v_2. From Newton's work it follows that the force F required to maintain the two planes at velocities v_1 and v_2, is

$$F \propto A. \frac{v_2 - v_1}{x} \qquad \ldots\ldots\ldots\ldots \quad (1)$$

Since $\frac{v_2 - v_1}{x}$ is a velocity gradient, it can be written $\frac{dv}{dx}$ and (1) becomes

$$F \propto A. \frac{dv}{dx} \qquad \ldots\ldots\ldots\ldots \quad (2)$$

or

$$F = \eta A \frac{dv}{dx} \qquad \ldots\ldots\ldots\ldots \quad (3)$$

In equation (3), η is termed the coefficient of viscosity. Rewriting (3),

$$\frac{F}{A} = \eta \frac{dv}{dx} \quad \ldots\ldots\ldots\ldots\ldots \quad (4)$$

But $\frac{F}{A}$ is the shear force per unit area, and hence is in the nature of a stress - a shear stress. In modern usage, velocity gradient has been given the name "rate of shear" and its units are reciprocal seconds or Sec^{-1}.

If η is truly a constant, that is it does not change in relation to the stress S or the rate of shear R, then plotting a curve of S & R should result in a straight line passing through the origin. This is the behaviour to be expected of a true Newtonian fluid.

Non Newtonian fluids - With some fluids, there is a variation of η with the rate of shear. Such fluids are obviously not Newtonian in their properties and belong to a different class designated generally by the term "non Newtonian" fluids.

Starch pastes generally exhibit pseudoplastic flow properties, i.e. the rate of flow increases faster than the shearing stress.[27] The viscosities of such materials depend on the rate of shear at which the determination is made so that the whole range of viscosity values are obtained as the shear rate is altered and the viscometric designation then becomes "apparent viscosity" (η_a).

1.522 - Viscosity Measurement

Since the viscosity of size paste is a major factor governing the behaviour of any paste during both the preparation and the application stage, an extended study of the whole problem of viscometry was undertaken in order to select a suitable control instrument. The qualities looked for were:-
ease of sampling combined with rapidity of obtaining readings and reliability under varying temperature and shear conditions over a wide range of viscosities.

Interest in the pasting properties of starches and their rheological properties has been shown for many years. An extended series of measurements on 3% pastes has been reported by Richardson and Waite,[28] using capillary viscometers at a constant shearing stress of 100 dynes/sq.cm. The rate of shear was, accordingly, variable. Despite this limitation, the rise in viscosity with gelatinisation and the subsequent decrease in viscosity as the paste was agitated were clearly shown.

Farrow et al.[29] recognised the importance of studying starch pastes at known rates of shear so that apparent viscosity could be expressed at given rates of shear in terms of constants of a simple equation, independent of the kind of viscometer and its dimensions. They were able to obtain approximate co-relation over a limited range of shear rates, of viscosity measurements made in capillary viscometers of various dimensions and in a Couette type viscometer.

Maeder et al.[30] designed a high shear-rate viscometer of the capillary flow type and employed it successfully in evaluating the suitability of polyvinylacetate emulsion adhesives for use on a high speed paper gluing machine. A direct relation was established between viscosity of the adhesive at rates of shear comparable to those developed on the machine and thickness of the wet film applied by the machine.

Caesar[31,32] devised an instrument which provided a graphical record of the changes occurring during pasting process. In this instrument, the torque variation during stirring was measured by means of a recording wattmeter and the curves so obtained indicated the change in viscosity with gelatinisation, continued cooking, and cooling. The investigator concluded that modification of the starch was clearly evident from the shape of the curve, because each starch exhibited characteristic pasting properties. Tapioca, corn, potato and wheat starches were studied in these tests, and a concentration of 20 per cent was found most suitable for the instrument. This method is of considerable interest, but the concentration limit is somewhat high, and it is insufficiently sensitive at lower viscosities.

A rotating cylinder viscometer has been designed by Barham, Wagnor and Reed.[33] It consists principally of a rotating, doughnut shaped solution cup and a "free" cylinder concentric with and suspended into the solution cup. Viscosity is measured by evaluating the restoring torque which must be applied to prevent the suspended cylinder from rotating. The instrument also provides readings during the cooking process. Measurements were made on potato, tapioca, corn and kafir starches, and the shape of curve was found characteristic for the different starches.

Variations in shear rate in a non-Newtonian liquid flowing within a viscometer can give rise to errors of considerable magnitude if a value is assigned to the shear rate calculated on the basis of a Newtonian fluid. Such errors can often be eliminated by applying a correction term to the flow data which takes into account both the geometrical configuration of the viscometer and the flow properties of the fluid. However, the tedium of this procedure can be avoided if the viscometer is designed to reduce the shear rate variation to a level for which the correction term becomes negligible. McKennell[34] has described the methods of achieving this end.

Higginbotham[35] has described an instrument for recording the consistency of starch pastes by means of mechanical dynamometer. Data is obtained during the cooking process. Sago, tapioca, farina and corn starches of both unmodified and treated types were studied. The experimental results quite clearly distinguished between the pasting characteristics of the different products. Higginbotham preferred a pasting temperature of 99°C, for the reason that some starches, particularly unmodified corn and wheat, are said to gelatinise slowly and incompletely at 90°C, although the higher temperature is not comparable with mill conditions.

Müller[36] has discussed in detail an instrument called "Brabender Amylograph". Several workers[37,38] have made an extensive study of the pasting characteristics of various native and modified starches as shown by this Amylograph.

The more commonly used industrial viscometers cannot be used in starch paste studies without considerable uncertainty in the validity of measurements. For many years orifice or efflux viscometers have been used, of these the Scott[39] and the fluidity funnel[40] are typical. For rapid determinations on pastes of low viscosity, pipettes such as Dudley[41] are sometimes used.

The falling ball viscometer is inconvenient and time consuming to use, and the results are not reproducible with sufficient precision.[40] Non-Newtonian flow has been analysed by this method and theoretical expressions have been derived[42] for shear stress and rate of shear at the equator of the sphere.

From these expressions the exact flow curve for the solutions is obtained and hence the true viscosity. The authors found that the theoretical curves for several solutions agreed well with those obtained by Krieger et al.[43] using capillary method.

Commercial rotational viscometers of the McMichael[44] and Stormer[45,46] type need modification before they become suitable for starch paste measurements. Lack of proper temperature control is one of the more serious deficiencies of these instruments. Suitable modification of the Stormer viscometer has been described by Fischer and Lindsley.[47,48]

During recent years, an extensive study of the pasting characteristics of starches, and of methods for measuring these characteristics have led to the development of Corn Industries viscometer which has been described by Kesler and Bechtel.[49] They have shown the utility of this instrument in a study of the application of various starches for industrial use.[50] It was reported that by obtaining full knowledge of the effect of various factors in the cooking procedure and by an appreciation of the changes which result in pastes on cooling, a more perfect co-relation results between such laboratory testing and mill practice, and accordingly, the applicability of starch products for specific industrial uses may be determined with greater precision.

Another viscosity control apparatus for textile sizing solutions is described in a U.S. patent.[51] The apparatus comprises a viscometer and connected with it a pump for recirculating the size solution to maintain the viscosity within desired limits. Means are provided to keep continuous record of viscosity changes and to sound an alarm when the viscosity is not within predetermined limits.

From the above survey it became clear that the instrument most closely answering to postulated requirements would have to be of the rotational type and as a result a Ferranti Portable Viscometer has been adopted for process control involved in this work. The instrument is described briefly in a subsequent chapter dealing with experimental methods.

1.53 - Dried Size Films

In sizing and finishing fabrics, starches and similar materials are applied to the cloth in the form of paste. The cloth is then dried and the excess moisture contained in the paste evaporated.

An adhesive film formed in this manner may impart to the cloth strength, fullness, smoothness or other desirable characteristics. The measurement and control of these properties is, therefore, important in evaluating usefulness of any polymeric film in textile processing.

A survey of literature disclosed only a few reports on the physical properties of starch and gelatin films. However, several investigators have measured properties of thin films of other materials such as paint, varnish, glue, nitrocellulose, celluloid and cellophane. Since their work dealt with problems similar to those presented by modified starch film, a brief report of the work is included here.

McBain and Hopkins[52] determined the tensile strength of thin films of two grades of gelatin, glue and isinglass. The rate of loading was maintained constant as far as possible. The purified gelatin and the isinglass had the same strength (9,500 lbs. per sq. inch). One glue had a lower value, whereas commercial gelatin and the commercial glues gave values ranging from 12,200 to 12,800 pounds per sq. inch.

The tensile properties of thin films of potato, corn and sago starches have been measured by Neale[53] with an apparatus that automatically drew their load extension figures. The rate of loading was adjusted so as to be roughly proportional to thickness of the specimen. The films were tested at 20°C and at 34 and 64 per cent. R.H. The results showed that there was little difference between the elastic properties of these starches and that corn starch was only slightly stronger than potato and sago starches. Thick films were slightly weaker than thin films of equal area. In dry air the films were harder, somewhat stronger, and more brittle than in moist air. Films containing alkali were very brittle and small quantities of soap in the mixing caused considerable weakening. The addition of 3 per cent. glycerine had a softening effect without appreciable loss of strength or elongation, but 5 per cent. of glycerine produced a much weaker film. Castor oil and tallow softened and weakened films if more than 5 per cent. was added.

Schopper[54] measured the bending resistance of fabrics, paper, celluloid and metal foils in an instrument which holds the hanging test strip firm with a suitable weight and bends it to and fro through an angle of 180° until it breaks. The number of bends that a fabric or test strip will withstand is considered a measure of its durability. The author plotted the number of bends required to produce breaks, expressed as a logarithm, against the load expressed as the percentage of the breaking strength. By extrapolating the straight lines he obtained for each material the "ideal bending number" or number of bends producing break when the load is zero, and the "bending limit" or the load under which the material can withstand only two complete to-and-fro bends.

The strength of potato starch films was studied by Seck and Brem.[55] They dried their films at room temperature and tested them for breaking strength in strips 10 by 1 cm. at 65 per cent R.H. and 20°C on a Schopper tester. In all cases the breaking load was greater in the transverse than in the longitudinal direction, or at least as great. This, they explained, was due to the structure of film. However, with increasing concentration of paste, also increasing thickness of film, there was less difference in film strength in two directions.

Test which measures the resistance to bending has been described by Pierce.[56] This test he applied to films made from potato starch. His apparatus consisted of two similar parallel penduli, suspended by long non rigid threads and connected by the strip of film. They were set swinging symmetrically, bending the strip, back and forth. The resistance of the strip to bending or its flexural rigidity is calculated from the period of swing. He found that the rate of change of flexural rigidity was nearly the same from 30 to 80 per cent. R.H. but was considerably less in drier atmospheres. Increasing humidity caused the film to swell and the amount of swelling was greater in the thickness direction than in the length. On comparing the resistance to bending with film stretch results produced by Neale,[53] the author concluded that the same elastic property of the film is involved in bending as in stretching.

In order to investigate flexural fatigues of size films, Bekku[57] used a repeating flexural tester. He found that there was a following equation between load at free end (L) and number of cycles up to breakdown (S) -

$$S = e^{\frac{L-A}{B}}$$

The flexural fatigues of size films were estimated with constants A and B. To analyse the results, stress-strain curve and elastic recoveries of size films were measured, on an assumption that this phenomenon is one type of repeating fatigue under constant deformation. It was observed that the size films, whose elastic behaviours are entropic rather than energetic and whose characteristic elongations are larger, illustrate less flexural fatigue.

Fury[58] measured the breaking strength, elongation and folding endurance of films of starches and glues. He found that films made from same starch differed significantly in breaking strength and thickness. The two variables were also particularly co-related, that is, the breaking strength of starch film strips became greater as the thickness increased. Wheat, dasheen, corn, rice, sweet potato, canna and potato starches were used alone and in combination with borax, glycerine, soap and sulphonated castor oil. The films of these seven starches at one concentration of paste differed in thickness. Potato starch formed the thickest film, then canna, sweet potato, etc.

Sadao Kuwajima[59] prepared starch and carboxymethylcellulose (I) and polyvinyl acetate (II) films and measured their stress-strain properties and bending strength. He found that film strengths were practically identical. Film II showed very large elongation. With regard to bending, films I and II were stronger than starch film, specially film II, which was also the best in all tests. The same author also studied the influence of heating time on the properties of these films and found that the strength of starch film decreased on heating.

EXPERIMENTAL
METHODS

CHAPTER 2.

EXPERIMENTAL METHODS

2.1 MATERIALS

2.11 - Sizing Materials

Thin boiling starches and starch ethers commercially marketed under the names of 'Textiline', 'T-Gum' and 'Solvitose' were mainly used in the present work. Various brands of these materials were employed to give a wide range of sizing recipes of different viscosity values.

Other materials employed included sago starch (used in conjunction with modified starch obtained under the name 'Chieftain') and Globe Noredux. The term "Noredux" has been derived from the phrase 'no reducing sugars' and the reducing sugars in Globe Noredux grades are substantially below the average in conventional dextrines. This product is marketed under various grades to give wide range of viscosity values.

Polyvinyl acetate emulsion, commercially available under the name of "Vinamul" was incorporated in some of the sizing mixes. Table II shows various brands of Vinamuls employed in the present work and it can be seen that they differ mainly in their plasticiser content.

TABLE II

	Vinamul N 8107	Vinamul N 8114	Vinamul N 8120
Total solids content, %	54-56	54-56	54-56
Plasticiser content	7	14	20
Viscosity at 25°C, poises (Ferranti-rate of shear 161.8 sec^{-1})	0.4-0.6	0.4-0.6	0.4-0.6
pH	6.0-6.5	6.0-6.5	6.0-6.5

2.111 - Moisture in Starch Samples

For the determination of moisture in starch samples, a simple method was employed.[60] 10 gm. of the sample, in each case, was accurately weighed into a 250 c.c. Florence flask with a ground glass joint. The flask was then half filled with distilled xylol, fitted with a moisture trap and a reflux condenser. Xylol was gradually brought to boil and refluxed for about ten minutes until collection of water in the trap had slowed down. The contents were then vigorously boiled for half an hour. The amount of moisture was read from the graduations of the trap. Boiling was continued for ten minutes and reading taken again.

This process was continued until a constant reading was obtained from which moisture percent. in the sample was calculated.

Table III shows various starch products, which were used in the present experiments, with their moisture content.

TABLE III

(showing various starch products used)

Product	Type	% Moisture content
Solvitose HCT$_1$	Ether starches	14.0
Solvitose SN		15.6
Solvitose CG		13.5
Textiline N	Thin boiling starches	18.0
T-Gum		15.6
Globe Noredux D 1713	Chlorinated starch	10.5
Chieftain		13.9
Sago	Native starch	16.8

2.112 Swelling Power and Solubility of Starch Samples

Differential starch pick-up efficiency during application may be due, amongst other factors, to varying swelling power and solubility. For this reason the above characteristics were investigated following the method used by Leach et al.[26] An appropriate amount of starch (usually 10 gm.) was suspended in 180 ml. of distilled water in a centrifuge bottle. The suspension was mechanically stirred at a rate just sufficient to keep the starch completely suspended. The speed was kept low to avoid shearing the fragile swollen granules and consequent solubilisation of the starch. The bottle was lowered into a thermostat controlled water bath maintained at the desired temperature and held for 30 min., slow stirring being continued during this period. The bottle was then removed, wiped dry, and placed on the balance. The stirrer was removed, rinsed into the bottle with sufficient distilled water to bring the total weight of water present to 200 gm. (including moisture present in the original sample). The bottle was then centrifuged for approx. 20 min. at 1800-2000 r.p.m. (i.e. nearly 700 times gravity) using M.S.E. centrifuge. The clear supernate was carefully drawn off. An aliquot of this supernate was evaporated to dryness and the percentage of solubles calculated to dry basis. The remaining sedimented paste in the bottle was reweighed and swelling power calculated as the weight of sedimented paste per gm. of dry starch. This value was corrected for solubles to provide a measure of the swell of undissolved portion of the starch. Determinations of swelling power and solubility were run at temperature intervals of 10° C. over the pasting range of 40-90°C.

2.12 - Sizing Recipes

Suitable sizing recipes were devised following the advice of the manufacturers of sizing materials and of the carpet makers. Various size formulations which have been employed in the present work are shown in Table IV. Each formulation has been allocated a Roman numeral reference and these were retained throughout this work.

TABLE IV

(showing sizing recipes)

Recipe No.	Products	Concentration g/l
I	Solvitose HC.1	25
	Textiline N	100
II	Solvitose CG	45
	Textiline N	45
	Vinamul N 8114	55
III	Solvitose SN	95
	Vinamul N 8114	60.5
IV	Solvitose CG	90
	T-Gum	112
V	Solvitose SN	70
VI	Sago	26
	Chieftain	54
	Vinamul N 8107	33

Recipe No.	Products	Concentration g/l
VII	Globe Noredux D 1713	195
	Vinamul N 8120	17.5

2.121 - Viscosity Characteristics of Various Size Mixes.

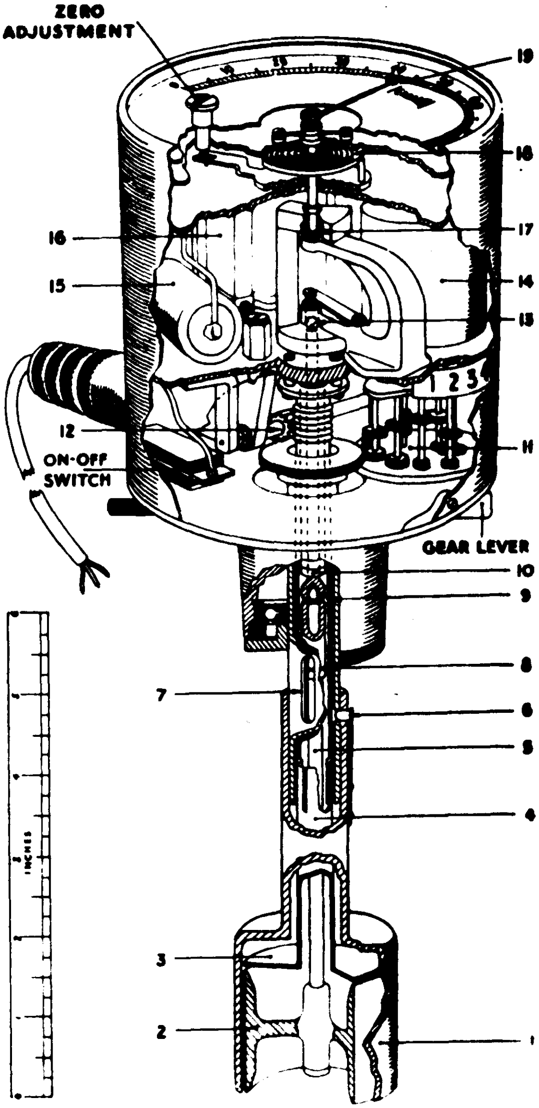
Since the amount of size picked up by carpets is dependent primarily not on concentration but on the viscosity of the size, thorough measurement and control of this characteristic becomes an essential stage in the process of application. This is particularly important when different types of size mixes are employed. When one type of starch alone is used, and size prepared and used in a standard manner, concentration serves as a rough measure of viscosity, and the loading of the material with paste follows the order of concentration.[61] In this work, where materials of vastly different types were employed, detailed knowledge of viscosity behaviour of all formulations used became imperative. This was particularly important since frequent duplication of exact recipes was necessary.

After thorough examination of the field of viscometry and the various viscometers available, it was decided to use a Ferranti rotational viscometer which would serve the best purpose in the present work as it permits measurement of viscosity of sizes at known rates of shear and at various temperatures up to 100° C, or with some modification even above that figure.

This instrument is of Couette co-axial cylinder type and is shown in Fig. 6. It consists of a rotating outer cylinder driven by a specially designed synchronous motor and an inner cylinder located co-axially within it. The inner cylinder is suspended in jewelled bearings and is free to rotate against a calibrated spring with a pointer to show angular deflection. The resulting rotation of the liquid in the annulus exerts a viscous drag on the inner cylinder causing a deflection proportional to the viscosity. The instrument is capable of being run at five different speeds and, therefore, viscosity measurements can be carried out at five different rates of shear.

The instrument used in the present work was fitted with a 40 gm. cm. spring and a set of three inner cylinders were provided to cover a range of viscosities up to about 6.2 poises. The outer cylinder of the louvred type was employed to provide continuous change of sample within the annulus.

Table V shows various shear rates and viscosity



KEY	
No.	ITEM
1	OUTER CYLINDER
2	INNER CYLINDER
3	GUARD RING
4	GUARD RING SUPPORT TUBE (DETACHABLE)
5	INNER CYLINDER SPINDLE
6	OUTER CYLINDER QUICK RELEASE ATTACHMENT
7	INNER CYLINDER RELEASE APERTURE
8 9	INNER CYLINDER QUICK RELEASE SYSTEM
10	STEADY BEARING
11	TURRET GEAR BOX
12	INNER CYLINDER LOCKING MECHANISM
13	SPRING LOADED SECONDARY BEARING
14	SYNCHRONOUS MOTOR
15	PHASING CONDENSER
16	TRANSFORMER
17	MAIN JEWELLED BEARING
18	TORQUE SPRING
19	VISCOSITY INDICATING POINTER

FIG. 6. SECTIONAL VIEW OF FERRANTI PORTABLE VISCOMETER

ranges that could be obtained with the use of the three inner cylinders.

TABLE V.

(Showing approx. viscosity ranges at different shear rates)

Inner cylinder	Speed rev./min.	Shear rate sec^{-1}	Approx. viscosity range. Poises.
Large	297.3	949.6	0.33
	248.2	791.2	0.4
	196.4	627.8	0.5
	148.6	475.0	0.67
	99.5	318.0	1.0
Medium	Same as above	327.7	1.1
		273.6	1.3
		216.6	1.6
		163.9	2.1
		109.7	3.2
Small	Same as above	203.75	2.1
		170.15	2.5
		134.7	3.2
		101.9	4.2
		68.23	6.2

The actual operation was carried out in accordance with maker's instructions and the instrument was found to give reliable and reproducible results over the full range available. Viscosity in poises at a given speed of cylinder combination was obtained by multiplying the instrument reading by the appropriate multiplying factor supplied by the manufacturers.

The investigation of viscosity behaviour of the various mixes is presented in two series of graphs, the first relating to the effect of rate of shear, the second to the effect of temperature.

Preparation of Paste: For preparation of paste for this study, the following method which reduces the variation from the operator to a minimum was used to secure the data:

To the weighed Solvitose component (in case of mixes containing Solvitose) cold water was stirred in slowly to prevent lumping and then other additions were made. 400 gm. of the paste was prepared in each case and this weight was obtained by addition of boiling water to the slurry. The size mix in a 500 c.c. flask was heated for 15 minutes in a boiling water bath, while being constantly stirred by a mechanical stirrer running at a fairly constant speed. During cooking each batch lost some water which was compensated for by addition of boiling water until the correct weight was obtained .

Where Vinamul was to be added, the mix was allowed to cool down to 80°C and then the required amount of Vinamul added.

Other mixes which did not contain Solvitose were also prepared in a similar fashion.

As soon as 15 min. cooking was completed and the loss of water compensated for, the paste was poured into a glass container which was placed in an electrically heated thermostated bath. Viscosity measurements were then carried out at various shear rates and at temperatures between 50°C and 90°C at an interval of approximately 5°C. (In case of mixes containing Vinamul, measurements were made between 50°C and 80°C).

2.13 - Carpet Samples

The specifications of various Spool Axminster carpet samples provided by the Federation of British Carpet Manufacturers are given in Tables VI and VII. Table VI gives the composition and Table VII shows settings and constructional details of the carpet specimens. The woollen counts are expressed as yds/oz., the staple viscose and the cotton counts as hanks of 840 yds/lb., the linen counts are leas of 300 yds/lb., and the jute yarn in spyndles (wt./14,400 yds. of yarn).

TABLE VI.

(Composition of carpet samples)

Ref.	Chain Yarn	Stuffer Yarn	Weft Yarn	Pile Yarn
A	3/12's cotton	7's Linen	12 Jute	50/2 yds. per oz. Wool.
B	3/12's cotton	7's Linen	21 Jute	" " " "
C	2/6's Fibro	2/6's Fibro	17 Jute	" " " "
D	2/6's Fibro	2/6's Fibro	17 Jute	50/2 yds. per oz. Fibro/Wool.
E	2/6's Fibro	2/6's Fibro	10 Jute	" " " "
F	2/6's Fibro	2/6's Fibro	10 Jute	" " " "
G	3/9's Cotton	3/9's Cotton	14 Jute	55/2 yds. per oz. Nylon/Wool.

Note: Each carpet sample has been allocated a capital letter reference used for identification purpose throughout this work.

TABLE VII.

(Settings and constructional details of carpet samples)

Ref.	No. of vertical rows of pile per inch.	No. of horizontal rows of pile per inch.	No. of tufts per sq.inch	Total length of tufts in inches.	Type of construction.
A	7	7½	52.5	0.88	Platt-3 shot Imperial
B	7	5	35.0	0.75	"
C	7	6	42.0	0.81	"
D	7	4 4/5	33.6	0.75	"
E	7	7½	52.5	1.0	"
F	7	6	42.0	1.0	"
G	7	6 2/3	46.7	0.81	Corinthian

2.2. PROPERTIES OF SIZE FILMS

2.21 - Formation of Films

2.211 - Preparation of Paste

Sizing recipes as mentioned under 2.12 were made into smooth pastes by an arbitrary procedure which is described as follows:

To the weighed main component, cold distilled water was stirred in slowly to prevent lumping and then other additions were made. 200 gm. of the paste was prepared in each case and the final weight was obtained by addition of hot distilled water. The sizing mixture in a 250 c.c. beaker was heated to boiling in 30 min. while being constantly stirred for first ten minutes by hand with glass rod. This was followed by mechanical stirring at constant speed for the remaining 20 minutes. During cooking each batch lost some amount of water which was compensated for by addition of boiling water till final weight required was obtained, (very slight error introduced by weighing the hot beaker being neglected).

In cases where Vinamul was to be added, the mixes were cooled to 80°C before addition of emulsion.

2.212 - Plating of Films.

A special technique of film casting was developed. Films were made by pouring the cooked paste slowly and evenly across a smooth thoroughly cleansed perspex tray (Fig. 7). Perspex was selected because it gave a surface from which the films released readily on drying. All pastes were poured out at about 80°C. in order to avoid deformation of the surface of the trays which took place at temperatures nearer to boiling point.

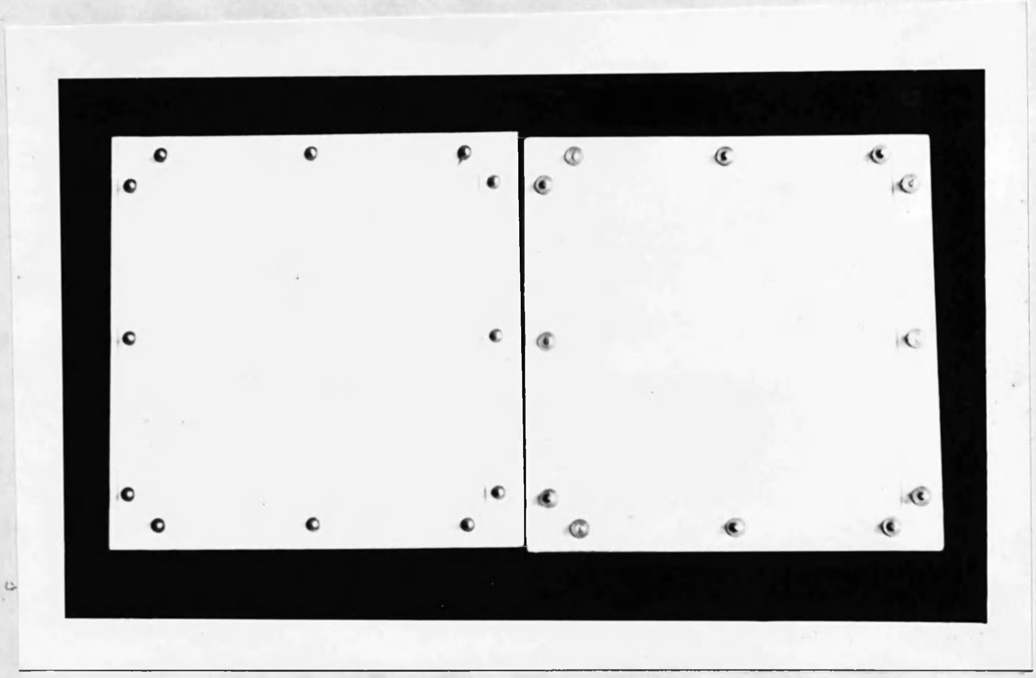


FIG. 7. FILM CASTING TRAYS

Since in determination of the physical properties of films thickness plays an important part, efforts were made to cast all films to give fairly constant dry thickness. To achieve this, an auxiliary experiment was performed in which total dry solids per unit area of the film were determined. In actual film casting, the amount of the paste flattened out on the tray was thus taken in such a quantity as to give the same amount of solids in the dried film with each size mixing.

Since in case of certain mixes, it was difficult to get uniform films because of the mix being very viscous, a decision was made to use the amounts of the products in the ratio of 40, 50 and 60 percent. of the original quantities. This assisted in producing pastes of a much more free flowing type without affecting the solids content of the dried film since the only thing changed was the degree of dilution.

The viscosity in poises for all the size mixings in the concentration of 40, 50 and 60 percent. at $80^{\circ}C$ and at various shear rates was determined using the rotational viscometer previously described. In duplicating the mixes, check was subsequently kept that they were of the same viscosity each time they were prepared for film plating.

2.213 - Drying and Conditioning of Films

Film casting trays were laid flat on a table in a humidity room at 65 percent. relative humidity and 20 ± 2°C. They were allowed to remain there for 24 hours or until the films were thoroughly dry. The dried films were then released from the trays and stored under standard conditions for a minimum of 24 hours before being tested.

2.22 - Determination of Physical Properties of Size Films.

2.221 - Tensile Strength and Extensibility.

Load-extension curves for films of sizing mixes were obtained on an Instron strength testing machine. Tests were made by grab method (jaw 1 in. wide) on films 2 in. wide and 5 in. long. Only films of uniform thickness were selected for testing. The thickness was measured at various points by an automatic micrometer gauge reading to one two-thousandths of an inch. The jaws of the Instron tester were clamped apart to accommodate a test length of 3 in. A constant rate of extension was used with a cross-head speed of 0.5 in./min. and the chart speed of 5 in./min.

All size films were tested under standard conditions, and the results conveniently expressed as:

(a) tensile strength, calculated per sq. cm. of
original area (kg. per sq. cm.)

(b) elongation at break, expressed as a percentage
of the original length.

All the experimental values shown were the means of at least 15 replica tests, for films of all sizing mixes.

2.222 - Bending Length and Flexural Rigidity.

Since the application of a starch paste in back-sizing a carpet should affect not only the strength of the material but also its rigidity, or resistance to bending, the measurement of this property was carried out on films of sizing mixes in order to be able to co-relate it, if possible, with its actual behaviour on the back of the carpet.

The instrument used for the measurement of bending length and flexural rigidity was the Shirley stiffness tester. This was very similar in principle to the instrument called 'Flexometer' used by Pierce.[62]

The film strip specimens to be tested were cut with a razor blade, accurately 15 cm. by 2.5 cm. The strip was then placed length wise on the platform of the instrument with one end coincident with the front upper edge of the platform. The slide was then pushed forward, carrying the specimen with it, until by looking into the mirror it was seen that the edge of the specimen was in line with two scribed lines. The operation was repeated with the remaining edges of the specimen. The observation to be recorded was the reading of the scale which gave directly the bending length (c). Flexural rigidity was then calculated from the formula

$$G = 0.10 \ w \ c^3 \quad \text{m.gm.cm.}$$

Where G = flexural rigidity
c = bending length in cm.
w = the strip weight in gm. per sq.meter.

The measurements were carried out under standard conditions and all the experimental values shown represent the average of at least 15 film strips tested.

2.223 - Flexing Strength

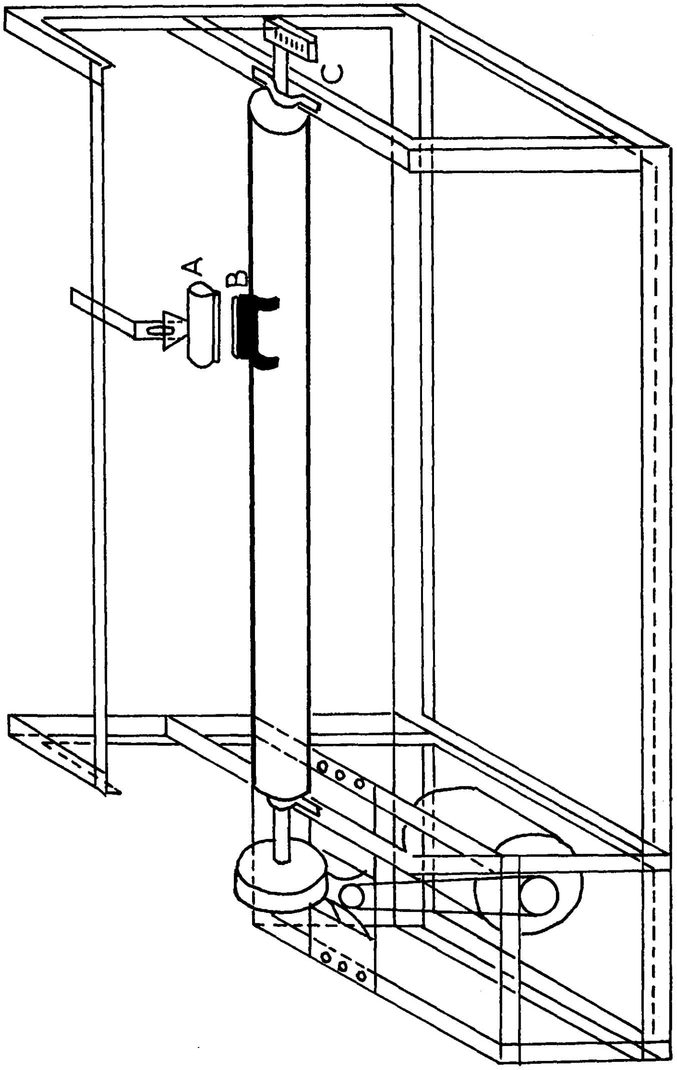
Ability of a film to flex without rupture represents an important aspect of suitability of any material for back-sizing purposes. The test for flexing strength of size films involved holding a strip of film suitably clamped and bending it repeatedly until it broke. The number of flexes required to break the film was considered a measure of pliability and toughness related to actual behaviour of sizes on the back of the carpet under normal wear conditions.

The instrument (Fig. 8) for flexing strength test was designed and consisted essentially of a stationary clamp for holding the film strip specimen and a rotating rectangular brass striker blade with square edges capable of bending film strip. The striker blade was fixed on a roller which was rotated by an electric motor at the rate of 175 r.p.m.

A revolution counter indicated the number of strikes necessary to rupture the film strip. The motor was stopped manually when the specimen broke.

The film strips 3 cm. wide used for the test were cut into lengths of 4 cm. The positions for the clamps were marked on the film strip with pencil and every effort was made to place the specimen straight in the clamps. The flexing strength or the number of revolutions required to rupture the specimen was recorded.

Due to non-availability of a sufficiently sensitive thickness gauge, it was decided to weigh film strips before being tested in order to find relation between weight of strip and the number of revolutions required to rupture it.



A - Clamping Device for Film Strip
B - Brass Striker Blade
C - Revolution Counter

FIG. 8. FLEXING STRENGTH TESTER

2.3 SIZE APPLICATION

2.31 - Preparation of Paste

Except for size mix II, all other mixes were employed in back-sizing of carpets. The omission of mix II was due to the fact that owing to the limited quantity of carpet samples available it was impossible to use all formulations.

Electrically heated 'Burco Boiler' was used as the size back. This was provided with a three heat control i.e. 'High', 'Medium' and 'Low'. Once the size paste was brought to boil, 'Low' heat maintained the paste at a suitable storage temperature.

The method of preparation was to add the main component first into cold water and to disperse it thoroughly. Other ingredients were then added and the mix made up to required weight. Vigorous hand stirring was maintained during the early stages of heating until the temperature had risen sufficiently to produce some swelling of the starch, and in this way perfectly smooth size free from lumps was prepared. In general it took about an hour to prepare the size paste and during this time it was stirred mechanically at a constant speed by a specially designed large bladed stirrer. The stirrer rod was passed through a hole in the centre of the cover of the boiler as this minimised loss of water due to evaporation.

Where Vinamul was to be added, the mix was allowed to cool down to 80°C prior to the addition of the emulsion.

2.32 - Control of Viscosity

A Ferranti Portable Viscometer (as described in 2.121) was employed to ensure that various carpet samples were run through the same mix at a constant viscosity. This was achieved by inserting the cylinders of the viscometer into the size trough and obtaining in this manner an instant and reliable reading at every point of the process.

2.33 - Method of Application of Size Mix

For application of size mix to the back of the carpet a small scale back-sizing unit was designed and constructed. The unit was designed to take a sample 6 in. wide and 6 ft. long (approx.) progressing at a range of speeds between ½ ft./min. to 2 ft./min.

Figure 9 represents a schematic diagram of the unit and Fig. 10 shows its photograph. The sizing zone consisted of a thermostatically controlled size box with an uncovered brass roller acting as an applicator.

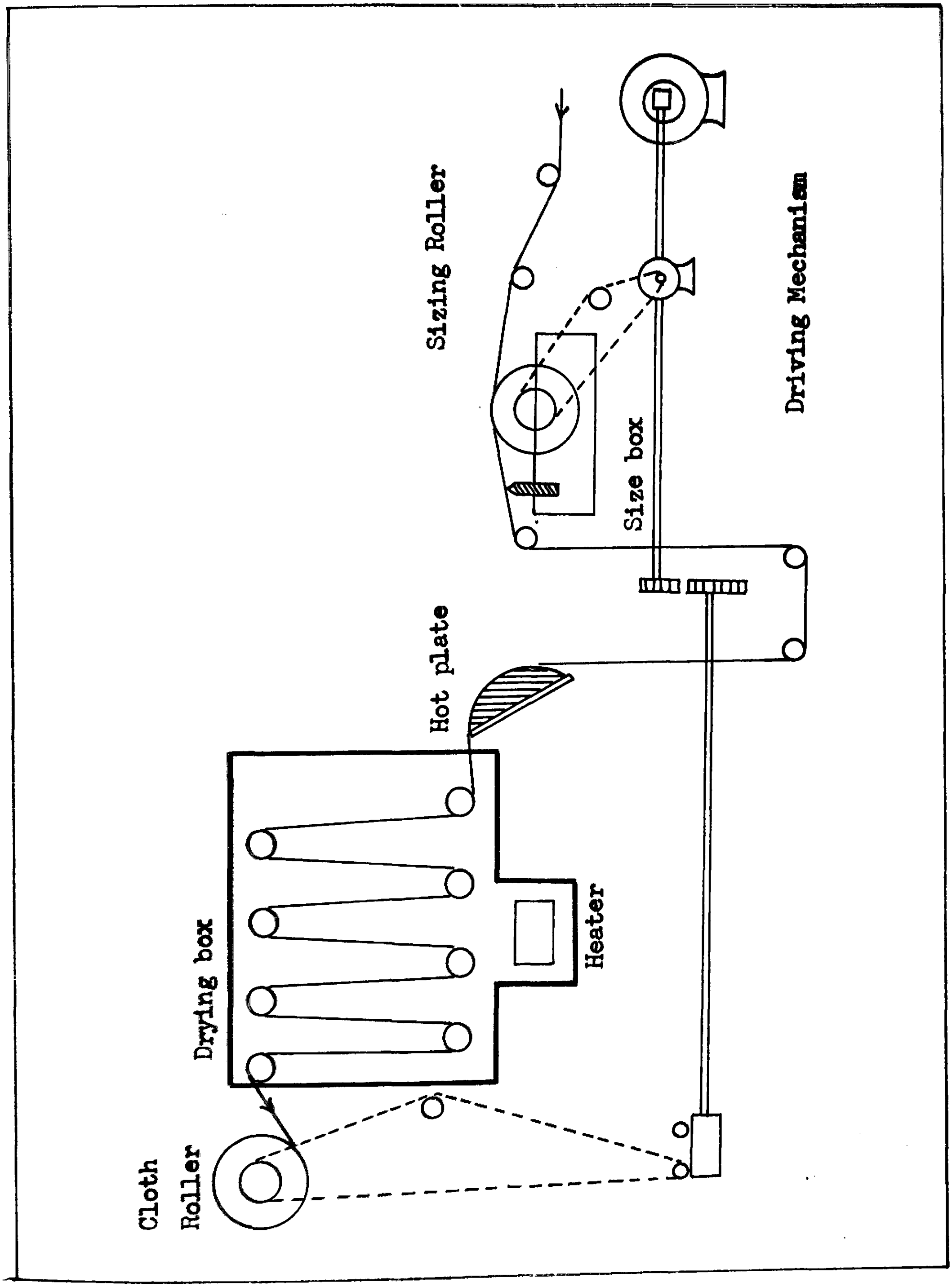


FIG. 9. SCHEMATIC DIAGRAM OF SMALL SCALE BACK-SIZING UNIT

FIG. 10. SMALL SCALE BACK-SIZING UNIT

The roller was positively driven by its own motor and had a very considerable range of speeds obtained by means of interchangeable sprockets. In addition, the drive also incorporated a gear box which gave either the forward or the reverse direction of rotation, the full range of speeds being available at each direction. The excess size was removed from the cloth by an adjustable doctor knife blade.

After leaving the doctor blade, the cloth was taken over a system of rollers until it reached a hot plate with a 250 watt element. This served as a predrying medium and allowed the cloth to enter the drying chamber already warmed. The chamber was itself heated by a 1 kw. - 2 kw. turbo heater. The maximum cloth carrying capacity of the chamber was about 12 ft. at any given time. However, if required this could be reduced by altering the path of the cloth.

Carpet samples to be sized were cut into lengths of about 4 ft. by 6 in. wide and were provided with hessian cloth as end pieces. Size mix prepared as described in 2.31 was transferred to the size trough and maintained at the desired temperature. Size was applied to carpet specimens at about 90°C except in case of mixes containing Vinamul which were applied at about 80°C.

Each mix was applied to at least four different carpet specimens. Immediately after sizing one sample, the other sample was run through the mix. In order to compensate for the mix taken out by the previous sample, fresh size mix was added to the trough. Care was taken to see that all the specimens through the same mix were run with the minimum fluctuations of temperature and viscosity.

The application roller was driven in all cases in the direction of the cloth travel which progressed at a speed of ½ ft./min. In case of carpet samples containing cotton and linen yarn in the backing, the application roller was run at approx. 90-95 r.p.m., while in case of fibro yarn, the speed was kept at approx. 25-30 r.p.m. to counteract higher wicking up property of these yarns. With the roller dia. of 3 in. approx. surface speeds obtained were 70 ft/min. and 20 ft/min. respectively.

2.4 TESTING OF CARPET SAMPLES

A programme of testing was devised to evaluate the contribution made by various size mixtures to the strength of tuft anchorage and to the stiffness of Axminster carpets. Data was obtained for comparative purposes from

(a) untreated samples, (b) sized samples, and (c) sized samples in which the backing was subjected to an arbitrary form of wearing action.

2.41 - Determination of the Amount of Size Added

Size pick-up of a sized carpet was determined from the loss in weight on removing the size completely.

Carpet specimens 3" x 3" (or 4" x 4" in cases where samples permitted such size to be taken) were placed in stoppered bottle of known weight (a). The weight of these containers was obtained by heating to constant weight condition at 105-110°C. Specimens were also dried at this temperature till constant weight (b) was obtained.

The samples were then desized by placing in a bath containing 1% Nervanase solution (an enzymatic desizing agent) on the weight of the material for nearly 2 hours. Desizing temperature was maintained at approx. 60-65°C. The samples were then washed as thoroughly as possible with hot distilled water until free of size and dried at 105-110°C to constant weight (c).

The difference (b - a) gave the weight of dry sized specimen and (c - a) that of desized specimen. The weight of the dry size was thus obtained from the difference between (b - a) and (c - a), i.e. (b - c) gave the amount of dry size. From this the amount of size in ozs. per sq. yard of carpet specimen was determined.

2.42 - Wear Testing

A number of machines [63.64,65] have been developed in the past for the assessment of wearing properties of carpets. Attempts have also been made to develop a machine [66,67] which would simulate walking. It is generally accepted that no one machine or abradent can possibly simulate all the kinds of wear to which a carpet might be subjected and that with the development of numerous machines there has arisen a need to standardise both the machines and the methods of test so that the carpets can be tested on a comparative basis. Most of these methods strive to evaluate wear resistance of the surface pile; in the case of this work, however, it was decided to act upon the back of the carpet in order to break down the size film partially. It was felt that this method would serve best to assess the value of a given size mix as a quality improving agent not only immediately after application but also in conditions simulating prolonged use and severe wear.

The wear tester selected for these experiments was one of the most recent developments in carpet testing apparatus, known as the Bocking Tetrapod Walker [68,69] or B.T.W. machine. This consisted of a drum 8 inches in diameter by 9 inches deep which was closed at one end and was lined with the sized carpet to be tested. Into this drum was placed the tetrapod, a heavily built tumbler consisting of four P.V.C. covered domes of specified hardness. Once the drum was filled, its other end was sealed and it was connected to a motor which rotated it about the horizontal at the speed of approx. 50 revolutions per minute. The drum was rotated for an arbitrary period of 24 hours after which the carpet was tested for tuft anchorage and stiffness.

2.43 - Determination of Tuft Anchorage

The method of measurement and assessment of tuft anchorage which was used throughout the present work was based on the use of Instron strength tester and has been described by Van Issum [70,71] and in the F.B.C.M. Bulletin.[72] In this the jaws of the Instron had to be modified so as to permit the testing of carpet samples. Figures 11 and 12 represent the modified pulling jaw in the closed and open positions respectively. The modified pulling clamp consisted essentially of two jaws which, when closed formed a platform on which the sample was placed and tested.

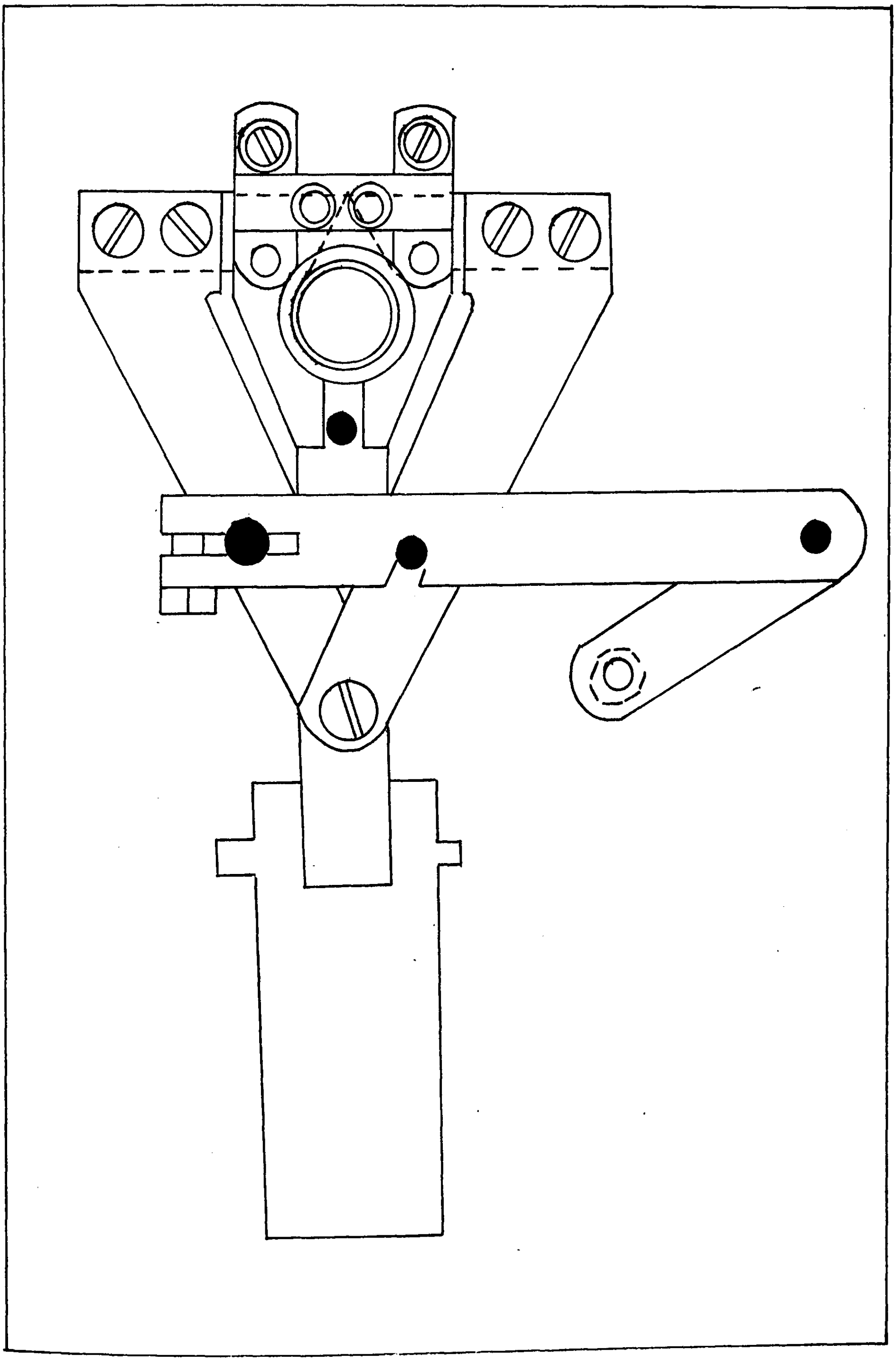


FIG. 11. PLATFORM FOR TUFT ANCHORAGE TESTING - CLOSED POSITION

(Used in conjunction with the Instron Strength Tester)

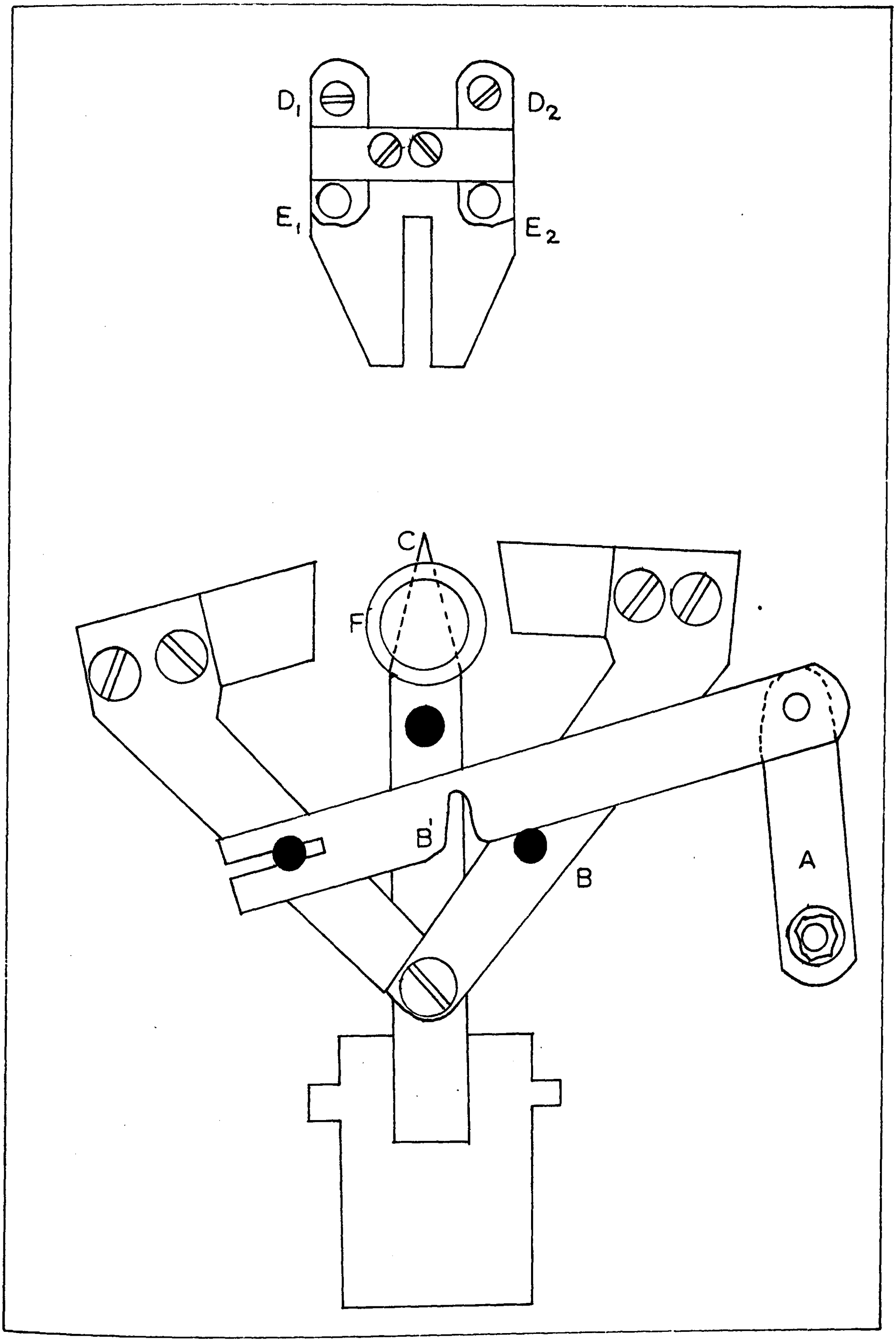


FIG. 12. PLATFORM FOR TUFT ANCHORAGE TESTING - OPEN POSITION

(Used in conjunction with the Instron Strength Tester)

The two jaws which constituted the platform could be separated by lifting the lever A and were locked together by lowering the same lever so that the protruding stud B fitted into the cut-away. The wedge C facilitated the separation of a single tuft. The sample was bent over the apex of the wedge so as to make a row of tufts stand out above the rest, thus enabling easy selection and separation of any particular tuft. The holding piece was detachable from the platform as seen in Fig. 12 and consisted primarily of two holding bars D_1 and D_2, pivoted at E_1 and E_2, thus enabling the holding bars to serve two purposes. First, the holding bars were used to hold the sample in position while it was bent over the wedge and second, they held the sample down while tuft was being withdrawn. The height of the holding bars above the platform was determined by the depth of pile, i.e., the greater the depth of pile, the higher the holding bars above the testing platform. The position of the holding bars was adjusted by slackening the screw F, adjusting the height of the holding bars and then tightening the screw back.

The gripping clamp was very simple in design and consisted of a clip, the jaws of which could be pressed tightly. This gripping clamp was attached to the tension cell of the Instron by means of a long rod.

The lengths of the carpets to be tested were cut to convenient size samples, i.e. approx. 6 inches long and 2½ inches wide. Generally six tests from five such strips gave thirty tests in all from which the mean tuft withdrawal force and other statistical data were determined.

Since it was shown by Van Issum [70] that there was no significant difference between the mean tuft withdrawal force at three different traverse speeds of the cross-head, the present experiments were carried out with a cross-head speed of 12 in/min. as it hastened the operation of testing.

Tuft anchorage test was carried out on unsized and sized carpets. Tests were also made on sized carpets after subjecting them to wear. All the specimens were conditions at 65 percent. R.H. and 20°C and the test was performed under similar conditions.

2.44 - Determination of Bending Length and Flexural Rigidity

The method used for the determination of these properties was very similar to the one described for size films under 2.222, except that in the apparatus employed, arrangement was made for the samples to bend at different angles depending on their stiffness. The bending length and flexural rigidity were then calculated using the following formula for rectangle bending under its own weight developed by Pierce.[62]

$$S = L^3 \frac{\cos 0.5\,\theta}{8 \tan \theta}$$

where $S = c^3 = \frac{G}{w}$

c = bending length in cm.

G = flexural rigidity in m.gm.cm.

w = wt. of the specimen in m.gm. per sq.cm.

L = overhanging length of the specimen in cm.

θ = angular deflection from the horizontal.

The test was carried out under standard conditions on unsized and sized carpets. It was also performed on sized samples after subjecting these to wear treatment.

Five specimens of 6 in. by 1 in. were cut from the carpet samples to obtain a representative value of bending length and flexural rigidity for each quality of carpet and size mixture.

CHAPTER 3.

EXPERIMENTAL RESULTS

3.1 - RESULTS FROM TESTS ON BACKSIZING AGENTS

Comments appearing under the various headings in this chapter are in the nature of explanatory notes referring to the face values obtained in the experimental work. No attempt has been made at this point to present the reasons for the sundry phenomenon observed, or to relate their interdependence. A full discussion and survey of the situation will be given in the final chapters.

3.11 - Swelling Power and Solubility of Individual Starch Samples

Tests of the above properties were made to define more fully the sizing materials used in the present work. Furthermore, it was considered necessary to have this data available since it is well known that swelling power and solubility may affect the behaviour of any mix with regard to penetration, weighting and other important aspects.

Figure 13 shows swelling patterns of various samples from which it is evident that almost all of them commence to swell at the same temperature, but thereafter the swelling proceeds at different rates. Solvitose CG undergoes a very rapid swelling at relatively low temperature. T-Gum and Chieftain show two stage swelling which has also been shown to occur with white milo (waxy sorghum) and regular milo starches.[26] The only starch sample which has been used in the present study and is not included in Fig. 13 is Solvitose HCT_1. It has been found that the latter sample swells very markedly at very low temperatures.

When solubilities of these starch samples are plotted against their pasting temperatures, the resulting curves (Fig. 14) are very similar to their swelling patterns. Here again, T-Gum and Chieftain show two stage solubilisation.

Further on plotting the swelling power against percentage solubles (Fig. 15), an interesting comparison of the solubility of these samples at equal levels of swelling is obtained. Thus, despite the high swelling power of sago starch at high temperatures, it is much less soluble at any particular degree of swelling.

3.12 - Viscosity Characteristics of Various Size Mixes

Figures 16 - 21 show the effect of rate of shear on the viscosity of sizing mixes II to VII through a cycle of temperature changes. All the mixes give a curved line, the curvature being such that the apparent viscosity decreases as the shear rate increases. Curves for mixes IV and VII are less steep than those for other mixes, indicating that these mixes are less affected by variation in shear rate conditions. At high shear values (above 600 sec^{-1}) curves for mix VII tend to straighten out.

In general, it is shown that the effect of rate of shear on the viscosity of sizing mixes is considerable. Thus satisfactory measurements can be made only when the rate of shear is constant, or when its magnitude can be determined or specified. In the absence of these conditions, many measurements will be virtually of no importance.

The viscosity of mix I was beyond the range of the instruments employed, which could measure viscosity up to 6.2 poises. As has been shown in an experiment on swelling and solubility of sizing materials, Solvitose HCT_1, which is component of mix I, swells to a very large extent and hence would produce very thick pastes when cooked in water. It is likely that the degree of modification of this product, which is manufactured by etherification of potato starch, is less, and therefore like potato starch, it swells to a considerable extent. As shown in table IX, when the products of this mix were taken in the proportion of 40, 50 and 60 per cent. of the original quantities for formation of films, it gave mixes of 0.28, 0.42, 0.64 poises respectively, at a shear rate of 327.7 sec^{-1} and at 80°C. Thus each increment in concentration resulted in a greater increase in viscosity than the preceding one. Bechtel and Fischer[73] also observed that when starch concentration is increased, the rate of rise of curve is more rapid and the maximum in the curves occurs at low temperatures.

Since, of all the physical conditions, temperature is the most serious in its effect on viscosity values, changes in viscosity resulting from changes in temperature are shown in Figs. 22 - 27. In case of some mixes temperature v/s viscosity curves have been plotted for only two or three shear rate variations, because some of the points would lie so close to the others that they could not be shown. It is apparent from these figures that a slight variation in temperature will lead to a considerable variation in viscosity. These observations bring out the importance of temperature control in sizing process in relation to a regularity of finish.

For comparison purposes, viscosities of various sizing mixes employed are shown in table VIII. The values reported in the table are at the shear rate of 203.75 sec^{-1} and at 80°C.

TABLE VIII

Mix No.	Viscosity, poises
II	0.36
III	0.62
IV	0.63
V	0.20
VI	0.27
VII	0.09

3.13 - Viscosity of Mixes for Formation of Films

In table IX are reported the values for viscosity in poises for all the mixes in the concentrations used for casting films.

TABLE IX

Mix No.	% of original mix	Viscosity, poises
I	40	0.28
	50	0.42
	60	0.64
II	40	0.030
	50	0.048
	60	0.068
III	40	0.033
	50	0.048
	60	0.055
IV	40	0.037
	50	0.053
	60	0.082
V	40	0.023
	50	0.032
	60	0.039
	70	0.053
	80	0.058
VI	40	0.026
	50	0.039
	60	0.048

Viscosity for each mix was measured at 80°C and at various shear rates, but for convenience the values shown in the table are for shear rate of 327.7 sec^{-1} for all mixes.

3.14 - Tensile Strength and Extensibility

It was observed that films made from the same sizing mix differed significantly in breaking strength and this was mainly due to variation in film thickness. In the techniques employed in the present investigations, the amount of the freshly prepared size paste was taken for film casting in such a manner as to give films of same thickness each time. However, due to viscous nature of the paste, it was difficult to obtain completely uniform distribution of paste in a given area. Thus variation in breaking strength and thickness among the films of the same sizing mix constitutes an unavoidable experimental error.

In no case were film strips kept for more than six days before testing and they remained in the humidity room under the test conditions from the time the paste started to dry on the plates up to the time the films were tested. This was necessary to prevent differences due to variations in moisture content.

For, as Swan[74] has shown, the water content of a size film at any given humidity is greater than that of a similar but dry film that has been allowed to complete its absorption in the same atmosphere.

Though it was realised that no direct comparison could be made between breaking strength of films without making adjustments for their thickness, however, it was found that the average values for thickness obtained for films of different mixes did not vary to a very great extent.

In table X, six sizing mixes have been compared for thickness, breaking strength and elongation. In calculating average values for films of different sizing mixes for various concentrations, the value for 40% concentration is omitted for mix I, which, due to films being very thin, gives abnormal breaking strength values. With this mix, great difficulty was experienced in obtaining uniform distribution of size paste owing to its very viscous nature (see table IX). The inaccuracies resulting from this difficulty are plainly seen in the increased standard errors of breaking strength values produced by this mix as compared with those produced by other sizing mixes.

TABLE X

Sizing Mix No.	% of original mix	No. of breaks	Average thickness (cm.x 10^{-3})	Tensile strength at break kg./cm^2	% Elongation
I	40	18	2.70	303± 20	1.43±0.08
	50	20	3.51	216± 12	1.47±0.06
	60	18	3.25	220± 17	1.17±0.07
	Av. values	56	3.38	218	1.32
II	40	14	3.78	118± 5	2.27±0.10
	50	15	4.09	114± 5	2.30±0.15
	60	18	3.84	128± 5	2.70±0.10
	Av. values	47	3.90	120	2.42
III	40	15	3.20	150± 6	2.13±0.06
	50	15	3.53	141± 5	1.80±0.05
	60	24	3.51	158± 4	2.23±0.05
	Av. values	54	3.41	150	2.05
IV	40	18	3.45	246±13	1.93±0.08
	50	21	3.35	282±10	2.0 ±0.06
	60	20	4.04	306±11	2.23±0.06
	Av. values	59	3.61	278	2.05
V	40	21	3.15	305±10	1.97±0.06
	50	18	3.45	269± 8	1.93±0.05
	60	17	3.48	283± 8	2.0 ±0.07
	70	19	3.48	271± 8	1.70±0.05
	80	24	3.61	232± 7	1.50±0.04
	Av. values	99	3.43	272	1.82
VI	40	21	3.47	325± 8	3.30±0.13
	50	23	4.10	260±10	3.0 ±0.19
	60	19	3.31	336± 9	2.80±0.09
	Av. values	63	3.63	307	3.03

As can be seen from table X, films of mixes II and III are softer than those of other mixes, since they give lower breaking strength and higher ultimate elongation. Next in order of softness are the films of mix I. In general the values obtained for breaking strength and elongation are lower than those obtained by Neale[53] for native starches.

In order to investigate the effect of concentration on breaking strength, films of mix V were additionally prepared and tested in 70 and 80 percent. concentration of the original mix. This particular mix was selected for this purpose, because of its simple composition. From the values obtained for thickness and breaking strength for various concentrations, it appears that it is the thickness which is mainly responsible for variation in breaking strength. Figure 28 shows decrease in breaking strength with increase in thickness for this mix.

Total elongation: Films of various sizing mixes differed in total elongation. In general, addition of Vinamuls to mixes resulted in greater total elongation. It has been shown that additions of softeners such as glycerine and sulphonated castor oil to native starches increases their total elongation[58] and the present results appear to be in agreement with this observation.

3.15 - Effect of Ageing on the Strength of Films

It was of interest to ascertain whether ageing of the films prior to testing had any effect on their breaking strength. Accordingly, film strips of some sizing mixes were stored for over a fortnight before being tested. The results obtained with these films are shown in table XI.

No marked differences were brought to light by storing films for a longer period, though from the values it appears that films of mixes I and V have become "harder", as evident from their greater breaking strength values (av. values). However, the values for average thickness of these films are lower than those of similar films conditioned for up to six days (Table X) and it is seen that thinner films of these two mixes are stronger. Hence slight increases in breaking strength values as observed for films of mixes I and V may be attributed to their thickness differences.

TABLE XI

Mix No.	% of original mix	No. of breaks	Average thickness (cm.x 10^{-3})	Tensile strength at break kg./cm^2	% Elongation
I	40	15	2.51	309 ± 23	1.43 ± 0.07
	50	12	2.67	250 ± 22	1.13 ± 0.09
	Av.values	27	2.59	280	1.28
III	40	10	3.20	159 ± 7	1.97 ± 0.07
	60	10	3.37	159 ± 6	2.10 ± 0.09
	Av.values	20	3.30	159	2.04
IV	40	10	3.33	226 ± 25	1.73 ± 0.09
	50	14	3.58	266 ± 17	2.10 ± 0.12
	60	18	4.0	301 ± 17	2.03 ± 0.09
	Av.values	42	3.64	264	1.95
V	40	9	3.15	330 ± 22	1.97 ± 0.10
	50	9	3.45	316 ± 20	2.13 ± 0.06
	60	10	3.37	335 ± 13	1.97 ± 0.06
	70	15	3.38	294 ± 13	1.57 ± 0.05
	Av.values	43	3.34	319	1.91

3.16 - Bending Length and Flexural Rigidity

As in the case of breaking strength and elongation tests, films of various sizing mixes were conditioned for up to six days before being tested. Table XII shows values for bending length together with their standard errors and for flexural rigidity.

It has been observed that bending length is dependent on the weight of film strip specimens, the heavier the specimen, the greater is the length necessary to ensure required bending; or, in other words, this property is dependent on the thickness of the specimen. As an illustration this has been shown in Fig. 29 for films of mix V and the same is true for films of other mixes.

Table XII shows that of all the sizing mixes, films of mix II give the lowest values for c and G, in spite of the average thickness of these films being greatest. Films of mix III stand next in order of increasing stiffness. This is, of course, an expected effect, for these mixes contain Vinamul emulsion.

The importance of addition of Vinamul to size mixes is further accentuated by the values of c and G for films of mixes III and V. Both these mixes contain

TABLE XII.

Mix No.	% of original mix	No. of strips tested	Average thickness (cm. x 10^{-3})	Bending length (cm.)	Flexural rigidity (m.gm.cm.)
I	40	17	3.05	2.25±0.06	43.35
	50	18	2.68	2.02±0.07	29.46
	60	17	2.37	2.0 ±0.05	29.42
	Av.valves	52	2.70	2.09	34.74
II	40	18	3.56	1.57±0.03	14.74
	50	11	4.06	1.73±0.05	19.21
	60	17	4.09	1.63±0.04	16.95
	Av.values	46	3.90	1.64	16.97
III	40	22	3.36	1.92±0.05	28.61
	50	15	3.30	1.7 ±0.04	19.61
	60	23	3.10	1.68±0.03	17.66
	Av.values	60	3.25	1.77	21.96
IV	40	15	3.38	2.05±0.03	28.61
	50	16	3.49	2.34±0.03	49.09
	60	18	4.12	2.57±0.05	69.56
	Av.values	49	3.66	2.32	39.09
V	40	14	3.15	2.3 ±0.06	47.37
	50	18	3.23	2.19±0.02	42.17
	60	17	3.56	2.26±0.03	44.84
	Av.values	49	3.31	2.25	44.79
VI	40	19	3.38	2.11±0.03	37.69
	50	16	3.80	2.28±0.05	47.12
	60	18	4.17	2.30±0.04	49.64
	Av.values	53	3.78	2.23	44.82

the same Solvitose component, i.e. Solvitose SN, but mix III in addition contains Vinamul N 8114. The lower values for c and G for films of mix III as compared to those of mix V underline the softness imparted by Vinamul N 8114 to the formulation. Thus, the view that addition of Vinamul to size mixes causes the films to become softer is further supported by these results having been previously established by tensile strength tests.

No marked differences are established for films of other sizing mixes, because any differences that exist (table XII) can be attributed to variation in their thickness values.

3.17 - Flexing Strength

A preliminary experiment on the flexing strength of size films revealed a considerable variation among the films of the same size mix and this was presumed to be due to the variation in thickness values. Due to non-availability of a very sensitive thickness gauge required for the purpose, it was decided to weigh the film strip specimen (4" x 3") and to find if any relation existed between the weight of the film strips and the number of revolutions required to rupture the film, i.e. flexing strength.

TABLE XIII

Mix No.	Wt. of film strips (gm.x 10^{-2})	Mean Weight (gm.x 10^{-2})	Flexing Strength (No.of revolutions)
I	3.0 - 3.5	3.25	405
	3.6 - 4.0	3.80	344
	4.1 - 4.5	4.30	303
	4.6 - 5.0	4.80	253
	5.1 - 5.5	5.30	182
II	3.8 - 4.0	3.90	930
	4.1 - 4.3	4.20	580
	4.4 - 4.6	4.50	482
	4.7 - 4.9	4.80	315
III	3.6 - 3.9	3.75	669
	4.0 - 4.3	4.15	544
	4.4 - 4.7	4.55	388
	4.8 - 5.1	4.95	332
IV	3.0 - 3.2	3.10	2626
	4.3 - 4.5	4.40	1417
	4.6 - 4.8	4.70	1263
	4.9 - 5.1	5.0	1174
	5.2 - 5.4	5.30	903
	8.1	8.10	88
V	3.5 - 4.0	3.75	1141
	4.1 - 4.5	4.30	676
	4.6 - 5.0	4.80	548
	5.1 - 5.5	5.30	435
	5.6 - 6.0	5.80	377
VI	3.5 - 4.0	3.75	1127
	4.1 - 4.5	4.30	997
	4.6 - 5.0	4.80	616
	5.1 - 5.5	5.30	591
	5.6 - 6.0	5.80	560
	6.1 - 6.5	6.30	550

Table XIII gives the weight in gm. and number of revolutions for the films of various sizing mixes. For convenience, those film strips which fall within, say 5 mg. difference, are grouped together and the average number of revolutions are calculated for them. The mean for each film is thus based on at least 8 to 10 measurements. Only one concentration (40% of the original mix) has been employed for flexing strength tests.

It is evident from the data in table XIII that flexing strength of all the films decreases as the weight of the film strips increases. On plotting the experimental values for number of revolutions required to rupture film strips against their corresponding mean weights (Figs. 30 and 31) the relation between two variables appears to be curvilinear for films of all sizing mixes. The heavier (or thicker) the film strip, the less flexing it will stand.

Furthermore, from Fig. 30, it can be seem that for the same weight of the film strip, there are considerable differences in flexing strength of the films of various sizing mixes. Films of mix I have the lowest flexing strength and those of mix IV (Fig. 31) the highest.

3.2 - RESULTS FROM TESTS ON CARPET SAMPLES

3.21 - Amount of Size Added

Data for the amount of size added to various carpet samples by different sizing mixes are shown in tables XV - XX along with the results for tuft anchorage tests. Each value shown for any particular carpet specimen is an average of the duplicate tests performed to determine the amount of size added.

It appears from the results that the amount of size taken up by a carpet sample depends on various factors, such as viscosity, amount of solids, swelling and solubility of the constituent products of the size mix. But since each sizing mix and each carpet sample used in the present work is different from the other, no exact relation is found between these variables and the amount of size added.

However, differences in the amount of size taken up at high and low viscosities are definitely shown by mixes I and VII, mix I being the most viscous of all and mix VII the least.

The evidence for the dependence of the amount of size taken up by the carpet sample on the amount of dry solids in the paste is borne out by mixes IV, VII and V.

As can be seen from the results, the maximum amount of size taken up by various carpet samples is from mixes IV and VII, both of which contain high proportion of solids as compared to other mixes. In general, with mix V, which has the lowest amount of solids in it, decrease of pick-up is observed in most of the cases.

Apart from the physical properties of sizing mix, construction of carpet specimens has an appreciable influence on the amount of size taken up from the paste. This is shown by Fig. 32, in which the amount of size taken up from three different sizing mixes is plotted against number of tufts per sq. in. of various carpet specimens. In plotting these curves, no account has been taken of the variation in the type of yarn in carpet backing and of the speed of the application roller. As can be seen from the figure, the amount of size added decreases with increase in the density of tufts. Another interesting feature of the curves is that they are steep up to about 40 tufts per sq. in. after which they tend to flatten out. This suggests that the maximum decrease in the amount of size added takes place between 30 and 40 tufts per sq.in. after which only slight differences occur.

3.22 - Tuft Anchorage: Prior to Wearing Action.

Each type of sizing mix possesses distinctive properties, which may be utilised in obtaining desired effects in carpet finishing. Data for the tests carried out to determine the effect of various sizes upon the tuft withdrawal force along with tests on unfinished carpets are embodied in tables XIV - XX. Data for the total amounts of solids picked up by various carpet specimens during sizing are also included in the tables. Percentage increase in tuft withdrawal force as shown in the results is calculated on the basis of figures for the unfinished carpets.

As can be seen from the tables, back-sizing process increases the tuft bind compared with the unsized carpet, but there is a considerable divergence of magnitude between various mixes. In general, it will be seen from the results that the greater the amount of size added, the better the improvement in tuft bind.

Figure 33 shows percent. increase in tuft withdrawal force of various sized carpet specimens plotted against various sizing mixes, which have been arranged in the order of increasing power of tuft binding. The only irregularity noticed is with sample E which shows some reduction in percent. increase in tuft withdrawal force with mixes IV and VII. Further, an interesting feature of the figure is that the carpet specimens which have more open structure (e.g. B, D. F) show much higher increase in tuft withdrawal force on sizing, confirming an expected trend.

Figure 34 shows relation between increase in tuft withdrawal force of various carpet samples and total dry solids in the size pastes. It appears from the figure that higher amount of solids in the mix causes greater increase in tuft withdrawal force. Some irregularity is shown by mix I which causes slightly smaller increase in tuft withdrawal force as compared with mix VI, in spite of the higher solids content of the former mix. In general, the nature of the curves is very similar to that of Fig. 33, indicating that one of the causes for the mixes to stand in that particular order is the total amounts of solids in the paste.

TABLE XIV

(Tuft withdrawal force for unfinished carpet specimens)

Carpet Sample Ref.	Tuft withdrawal force (gm.)	Std. deviation (gm.)	Std. error (gm.)	C.V. %
A	249	50	9	20
B	176	25	5	14
C	163	28	5	17
D	105	35	6	33
E	278	52	9	19
F	90	24	4	27
G	287	58	11	20

TABLE XV

(Tuft withdrawal force for different carpet specimens sized with mix I)

Carpet Sample Ref.	Pick up oz/sq.yd.	Tuft withdrawal force (gm.)	Std. deviation (gm.)	Std. error (gm.)	C.V. %	Increase in tuft withdrawal force, %
A	2.00	510	73	13	14	105
C	2.85	540	95	17	9	213
D	5.84	365	51	9	14	248
E	2.54	530	94	17	18	91
F	4.82	620	106	19	17	589
G	3.30	690	86	16	13	140

TABLE XVI

(Tuft withdrawal force for different carpet specimens sized with mix III)

Carpet Sample Ref.	Pick up oz/sq.yd.	Tuft withdrawal force (gm.)	Std. deviation (gm.)	Std. error (gm.)	C.V. %	Increase in tuft withdrawal force, %
A	2.14	720	147	29	20	189
B	3.43	1060	200	40	19	502
C	2.28	640	115	21	18	293
D	6.09	920	174	36	19	776
E	2.79	1120	268	49	24	303
G	4.57	1000	160	29	16	248

TABLE XVII

(Tuft withdrawal force for different carpet specimens sized with mix IV)

Carpet Sample Ref.	Pick up oz/sq.yd.	Tuft withdrawal force (gm.)	Std. deviation (gm.)	Std. error (gm.)	C.V. %	Increase in tuft withdrawal force, %
A	7.85	1013	149	27	15	307
C	5.59	788	125	23	16	383
D	9.64	950	150	27	16	805
E	5.07	1060	232	42	22	282
F	10.91	1320	312	57	24	1367
G	9.14	1480	150	27	10	416

TABLE XVIII

(Tuft withdrawal force for different carpet specimens sized with mix V)

Carpet Sample Ref.	Pick up oz/sq.yd.	Tuft withdrawal force (gm.)	Std. deviation (gm.)	Std. error (gm.)	C.V. %	Increase in tuft withdrawal force, %
A	3.43	345	61	11	18	39
B	5.84	390	61	11	16	122
C	3.43	320	45	8	14	96
D	5.07	480	105	19	22	357
E	3.05	550	115	21	21	98
G	3.3	410	73	13	18	43

TABLE XIX

(Tuft withdrawal force for different carpet specimens sized with mix VI)

Carpet Sample Ref.	Pick up oz/sq.yd.	Tuft withdrawal force (gm.)	Std. deviation (gm.)	Std. error (gm.)	C.V. %	Increase in tuft withdrawal force, %
A	4.38	620	80	15	13	149
B	4.57	730	64	12	9	315
D	4.57	725	105	19	15	591
E	3.05	588	143	26	24	112
F	-	875	128	24	15	872

TABLE XX.

(Tuft withdrawal force for different carpet specimens sized with mix VII)

Carpet Sample Ref.	Pick up oz/sq.yd.	Tuft withdrawal force (gm.)	Std. deviation (gm.)	Std. error (gm.)	C.V. %	Increase in tuft with drawal force, %
A	11.27	1013	144	26	14	307
B	13.19	1540	214	39	14	775
D	12.94	1260	327	60	26	1100
E	4.57	820	209	38	26	195

3.23 - Tuft Anchorage: After Wear

Samples of the sized carpets, conditioned at 65% R.H., were given a wear treatment in the tetrapod machine for 24 hours. After wear the samples were again conditioned at 65% R.H. and the effect of wear treatment was evaluated by determining the tuft withdrawal force. This is then compared with the tuft withdrawal force of a similar unsized and sized (but unworn) carpet specimen.

Results and the statistical data for the force required to withdraw tufts from the sized worn carpets are shown in tables XXI - XXVI. As in the previous results of tuft anchorage of sized but unworn carpet specimens, percentage increase in tuft withdrawal force has been calculated on the basis of figures for unsized carpets.

From the results it will be seen that the percentage increase in tuft withdrawal force after wear follows the same order as with sized unworn carpets. Thus mixes V and VII which seem to cause the minimum and maximum increase respectively, still retain that order after subjecting the sized specimens to wear.

For comparison purposes, the results for the unsized and sized (before and after wear) carpets are summarised in table XXVII. In this table the column for the percentage decrease in tuft withdrawal force has been calculated on the basis of figures for sized unworn carpets. With various carpet specimens, each mix appears to cause, in general, the same amount of decrease in tuft anchorage after wear. There are some deviations from this order, e.g. mixes I, V and VII with carpet samples D, B and A, respectively, show smaller decreases.

In general, an interesting feature of the results is that, even after wear, all carpet specimens sized with different sizing mixes show considerable increase in tuft anchorage as compared with the unfinished carpets. It can be observed, however, that during wear there occurs a very appreciable levelling out of figures for tuft withdrawal force and, as a result, the total spread of differences becomes much reduced.

TABLE XXI

(Tuft withdrawal force after wear for different carpet specimens sized with mix I)

Carpet Sample Ref.	Tuft withdrawal force (gm.)	Std. deviation (gm.)	Std. error (gm.)	C.V. %	Increase in tuft withdrawal force, %
A	370	81	20	21	49
C	370	70	18	19	127
D	330	69	15	21	214
E	370	81	16	22	33
G	410	89	18	22	43

TABLE XXII

(Tuft withdrawal force after wear for different carpet specimens sized with mix III)

Carpet Sample Ref.	Tuft withdrawal force (gm.)	Std. deviation (gm.)	Std. error (gm.)	C.V. %	Increase in tuft withdrawal force, %
A	430	98	20	23	73
B	500	71	16	14	184
C	340	69	14	20	109
D	470	111	22	24	348
E	490	116	23	24	76
G	580	108	22	19	102

TABLE XXIII

(Tuft withdrawal force after wear for different carpet specimens sized with mix IV)

Carpet Sample Ref.	Tuft withdrawal force (gm.)	Std. deviation (gm.)	Std. error (gm.)	C.V. %	Increase in tuft withdrawal force, %
A	683	149	30	22	174
C	500	113	23	23	207
D	600	113	25	19	471
E	740	125	25	17	166
G	1060	166	33	16	269

TABLE XXIV

(Tuft withdrawal force after wear for different carpet specimens sized with mix V)

Carpet Sample Ref.	Tuft withdrawal force (gm.)	Std. deviation (gm.)	Std. error (gm.)	C.V. %	Increase in tuft withdrawal force, %
A	255	67	13	26	2.5
B	380	75	17	20	116
C	225	29	6	13	38
D	340	94	24	28	224
E	340	84	17	25	22
G	310	60	12	19	8

TABLE XXV

(Tuft withdrawal force after wear for different carpet specimens sized with mix VI)

Carpet Sample Ref.	Tuft withdrawal force (gm.)	Std. deviation (gm.)	Std. error (gm.)	C.V. %	Increase in tuft withdrawal force, %
A	320	67	13	21	29
B	400	73	15	18	127
D	460	113	25	25	338
E	410	87	17	21	48

TABLE XXVI

(Tuft withdrawal force after wear for different carpet specimens sized with mix VII)

Carpet Sample Ref.	Tuft withdrawal force (gm.)	Std. deviation (gm.)	Std. error (gm.)	C.V. %	Increase in tuft withdrawal force, %
A	920	220	44	24	270
B	1140	191	38	17	548
D	980	208	47	21	833
E	630	105	24	17	127

TABLE XXVII

Size Mix No.	Carpet Sample Ref.	TUFT WITHDRAWAL FORCE (GM)			Decrease in tuft withdrawal force after wear,%
		Unsized	Sized before wear	Sized after wear	
I	A	249	510	370	28
	C	163	540	370	32
	D	105	365	330	10
	E	278	530	370	30
	G	287	690	410	41
III	A	249	720	430	40
	B	176	1060	500	53
	C	163	640	340	47
	D	105	920	470	49
	E	278	1120	490	56
	G	287	1000	580	42
IV	A	249	1013	683	33
	C	163	788	500	37
	D				
	E				
	G				
V	A				
	B				

3.24 - Bending Length and Flexural Rigidity of Carpet Samples

The above characteristics have been measured to determine the stiffness imparted to various carpet samples by different sizing recipes.

It is well known that woven fabrics have different properties in the warp and weft direction, because the yarns greatly differ in type, count, twist, number, crimp, etc., so there is no reason to expect a relation between the bending lengths measured in the two directions. In this work, measurements for bending length have been carried out in the warp direction only, as stiffness of the carpet specimens in the weft direction was so high that measurements could not be made with the technique employed in the investigation.

In all cases, the length of the overhang was so chosen as to give a deflection of $20^{\circ} - 30^{\circ}$, depending on the stiffness of the samples.

Bending lengths with standard deviations and flexural rigidity values obtained with various carpet specimens in the unfinished and sized (before and after wear) state are specified in tables XXVIII - XXXIII. In addition data for the amount of size picked up by various carpet specimens from different sizing mixes are also included in the tables.

It is seen from the results that values for bending length and flexural rigidity are higher for those unfinished carpet structures (similar in composition) which are more compact in construction. However, sample B is found to be stiffer than sample A, inspite of the fact that the former is more open in construction.

After sizing rigidity values show, as expected, a considerable rise. The effect of some mixes in a number of cases is so pronounced as to mask completely the inherent stiffness characteristics of the samples.

The tetrapod wear action appears to change the above situation markedly and many samples show a variety of effect oscillating between reasonably good and very poor retention of stiffness.

To facilitate better evaluation of the results, additional tables XXXIV - XXXIX have been included. These show the stiffness characteristics of a particular carpet specimen in the unfinished state and after sizing with various mixes.

TABLE XXVIII

(Bending Length (c) and Flexural Rigidity (G) values for various carpet specimens sized with mix I)

Carpet Sample Ref.	Pick up oz/sq.yd.	Unfinished		Sized but before wear		Sized after wear	
		c (cm)	G (m.gm.cm)	c (cm)	G (m.gm.cm)	c (cm)	G (m.gm.cm)
A	2.0	3.80±0.10	10,400	6.41±0.43	48,000	3.73±0.20	9,400
C	2.85	2.60±0.10	3,200	7.0 ±0.53	67,000	3.74±0.15	9,600
D	5.84	2.51±0.12	2,300	6.55±0.28	42,100	5.02±0.42	19,500
E	2.54	3.32±0.25	7,900	4.99±0.61	26,100	4.21±0.52	15,500
G	3.30	3.12±0.11	6,100	6.34±1.19	55,000	3.74±0.59	10,300

TABLE XXIX

(Bending Length (c) and Flexural Rigidity (G) values for various carpet specimens sized with mix III)

Carpet Sample Ref.	Pick up oz/sq.yd.	Unfinished		Sized but before wear		Sized after wear	
		c (cm)	G (m.gm.cm)	c (cm)	G (m.gm.cm)	c (cm)	G (m.gm.cm)
A	2.14	3.83±0.10	10,400	5.22±0.49	26,100	3.80±0.08	10,200
B	3.43	4.02±0.16	12,100	5.40±0.31	29,000	3.80±0.13	11,000
C	2.28	2.6 ±0.10	3,200	6.20±0.21	46,000	5.52±0.25	32,000
D	6.09	2.51±0.12	2,300	7.80±0.80	84,200	5.88±0.36	36,400
E	2.79	3.32±0.15	7,900	5.22±0.33	33,200	4.33±0.13	18,200
G	4.57	3.12±0.11	6,100	5.15±0.20	26,400	4.04±0.21	14,000

TABLE XXX

(Bending Length (c) and Flexural Rigidity (G) values for various carpet specimens sized with mix IV)

Carpet Sample Ref.	Pick up oz/sq.yd.	Unfinished		Sized but before wear		Sized after wear	
		c (cm)	G (m.gm.cm)	c (cm)	G (m.gm.cm)	c (cm)	G (m.gm.cm)
A	7.85	3.83±0.10	10,400	6.47±0.33	55,500	4.75±0.18	22,000
C	5.59	2.60±0.10	3,200	5.70±0.49	36,000	4.40±0.18	16,400
D	9.64	2.51±0.12	2,300	7.24±0.12	69,300	6.34±0.32	45,900
E	5.07	3.32±0.15	7,900	5.52±0.45	38,400	4.63±0.45	22,800
G	9.14	3.12±0.11	6,100	5.05±0.10	28,800	4.69±0.20	23,200

TABLE XXXI

(Bending Length (c) and Flexural Rigidity (G) values for various carpet specimens sized with mix V)

Carpet Sample Ref.	Pick up oz/sq.yd.	Unfinished		Sized but before wear		Sized after wear	
		c (cm)	G (m.gm.cm)	c (cm)	G (m.gm.cm)	c (cm)	G (m.gm.cm)
A	3.43	3.83±0.10	10,400	4.04±0.33	12,000	3.44±0.08	7,100
B	5.84	4.02±0.16	12,100	5.90±0.37	37,800	3.6 ±0.09	9,030
C	3.43	2.60±0.10	3,200	6.53±0.56	50,200	4.45±0.18	17,100
D	5.07	2.51±0.12	2,300	6.13±0.29	39,300	5.58±0.17	30,000
E	3.05	3.32±0.15	7,900	6.11±0.21	49,000	4.57±0.10	20,000
G	3.30	3.12±0.11	6,100	4.16±0.37	14,800	—	—

TABLE XXXII

(Bending Length (c) and Flexural Rigidity (G) values for various carpet specimens sized with mix VI)

Carpet Sample Ref.	Pick up oz/sq.yd.	Unfinished		Sized but before wear		Sized after wear	
		c (cm)	G (m.gm.cm)	c (cm)	G (m.gm.cm)	c (cm)	G (m.gm.cm)
A	4.38	3.83±0.10	10,400	5.28±0.27	28,000	3.44±0.28	7,500
B	4.57	4.02±0.16	12,100	6.10±0.13	42,000	4.04±0.29	12,000
D	4.57	2.51±0.12	2,300	6.59±0.21	47,400	5.52±0.07	27,400
E	3.05	3.32±0.15	7,900	6.11±0.15	48,300	5.28±0.13	31,300

TABLE XXXIII

(Bending Length (c) and Flexural Rigidity (G) values for various carpet specimens sized with mix VII)

Carpet Sample Ref.	Pick up oz/sq.yd.	Unfinished		Sized but before wear		Sized after wear	
		c (cm)	G (m.gm.cm)	c (cm)	G (m.gm.cm)	c (cm)	G (m.gm.cm)
A	11.27	3.83±0.10	10,400	6.94±0.27	71,000	4.99±0.30	26,300
B	13.19	4.02±0.16	12,100	6.80±0.50	73,000	4.98±0.30	29,000
D	12.94	2.51±0.12	2,300	7.39±0.21	77,800	6.06±0.24	44,600
E	4.57	3.32±0.15	7,900	5.34±0.15	36,200	4.51±0.48	20,900

TABLE XXXIV

(Flexural Rigidity (G) values for carpet specimen A sized with various sizing mixes)

Size Mix No.	Pick up oz/sq.yd.	Unfinished G (m.gm.cm)	Sized but before wear G (m.gm.cm)	Sized after wear G (m.gm.cm)
I	2.0	10,400	48,000	9,400
III	2.14	"	26,100	10,200
IV	7.85	"	55,500	22,000
V	3.43	"	12,000	7,100
VI	4.38	"	28,000	7,500
VII	11.27	"	71,000	26,300

TABLE XXXV

(Flexural Rigidity (G) values for carpet specimen B sized with various sizing mixes)

Size Mix No.	Pick up oz/sq.yd.	Unfinished G (m.gm.cm)	Sized but before wear G (m.gm.cm)	Sized after wear G (m.gm.cm)
III	3.43	12,100	29,000	11,000
V	5.84	"	37,800	9,030
VI	4.57	"	42,000	12,000
VII	13.19	"	73,000	29,000

TABLE XXXVI

(Flexural Rigidity (G) values for carpet specimen C sized with various sizing mixes)

Size Mix No.	Pick up oz/sq.yd.	Unfinished G (m.gm.cm)	Sized but before wear G (m.gm.cm)	Sized after wear G (m.gm.cm)
I	2.85	3,200	67,000	9,600
III	2.28	"	46,000	32,000
IV	5.59	"	36,000	16,400
V	3.43	"	50,200	17,100

TABLE XXXVII

(Flexural rigidity (G) values for carpet specimen D sized with various sizing mixes)

Size Mix No.	Pick up oz/sq.yd.	Unfinished G (m.gm.cm)	Sized but before wear G (m.gm.cm)	Sized after wear G (m.gm.cm)
I	5.84	2,300	42,100	19,500
III	6.09	"	84,200	36,400
IV	9.64	"	69,300	45,900
V	5.07	"	39,300	30,000
VI	4.57	"	47,400	27,400
VII	12.94	"	77,800	44,600

TABLE XXXVIII

(Flexural Rigidity (G) values for carpet specimen E
sized with various sizing mixes)

Size Mix No.	Pick up oz/sq.yd.	Unfinished G (m.gm.cm)	Sized but before wear G (m.gm.cm)	Sized after wear G (m.gm.cm)
I	2.54	7,900	26,100	15,500
III	2.79	"	33,200	18,200
IV	5.07	"	38,400	22,800
V	3.05	"	49,000	20,000
VI	3.05	"	48,300	31,300
VII	4.57	"	36,200	20,900

TABLE XXXIX

(Flexural Rigidity (G) values for carpet specimen G
sized with various sizing mixes)

Size Mix No.	Pick up oz/sq.yd.	Unfinished G (m.gm.cm)	Sized but before wear G (m.gm.cm)	Sized after wear G (m.gm.cm)
I	3.30	6,100	55,000	10,300
III	4.57	"	26,400	14,000
IV	9.14	"	28,800	23,200
V	3.30	"	14,800	—

CHAPTER 4.

DISCUSSION

4.1 - EFFECT OF RATE OF SHEAR ON VISCOSITY OF SIZE MIXES

The property of the decrease in viscosity with increasing shear rates is connected with the solvation, aggregation and swelling of colloidal particles.[27]

Oswald[75] has described numerous cases of colloids in which dispersed material is solvated to an extent which leads to marked swelling. Such particles because of their increased size, are considered to interact with each other to form some kind of internal structure and the term "structural viscosity" was adopted as descriptive of the flow properties of these systems. The use of this term has been extended to various types of non-Newtonian flow. The term pseudo-plasticity is widely used for such cases as those encountered in this work. There may be some question about appropriateness of the term pseudo-plastic but it is useful since it distinguishes this kind of flow from plastic, Newtonian and dilatant flow.

According to Fischer and Lindsley,[27] in the most common cases of pseudo-plasticity, the dispersed phase is lyophilic, i.e. capable of absorbing and swelling in the liquid phase. The particles thus are appreciably solvated and may be pictured as surrounded by an envelope of the colloid-liquid complex. In a material which is capable of forming a gel, the boundaries of one particle merge with those of adjacent particles. As the mixture is sheared, the particles are disturbed from an equilibrium condition and are deformed and oriented to some extent in the direction of flow. Some of the liquid associated with the particles may be separated, with the result that particles themselves are effectively smaller; consequently, interaction during shearing is reduced and hence there is a decrease in resistance to shear. As the rate of shear increases, the extent of such change in particle size becomes greater and as a consequence, the apparent viscosity falls. If a point were reached at which no further change in particle size occurred, then the relationship between viscosity and rate of shear would become linear and the straight line would be parallel to the shear rate axis.

4.2 - PHYSICAL PROPERTIES OF SIZE FILMS

4.21 - Tensile Strength and Extensibility

The load extension diagrams for films of various sizing mixes were rectilinear for small loads, but usually showed a rapid rise as breaking point approached. There was no definite yield point, and the curve appeared perfectly smooth. In general, the curves closely resembled those of moderately ductile metal such as copper.[76]

Fury[24] observed that the thicknesses of dried films stand in reverse order to the rates of flow of starch. Thus a starch paste having a high rate of flow makes a thin film and one of low rate of flow a thick one. From the results obtained in the present investigations no such relation is noted, though the sizing mixes employed are of widely varying viscosities. However, since thickness of dried films was considered to be the most important factor which would influence the physical properties of size films, effort was made to make films of same thickness from various sizing mixes, irrespective of their viscosity values. Because high viscosity tended to interfere with film forming properties, the concentration was reduced and films were cast from a larger volume of solution thus obtaining good flow characteristics without sacrificing the required solids content.

Neale[53] found that thick films of starch are weaker, while Fury[58] observed that breaking strength of starch film strip becomes greater as the thickness increases.

In the present work, no general trend could be found for films of different sizing mixes but each seemed to behave in an individual manner. For example, films of mixes I and V show increase in breaking strength with decrease in thickness while those of mix IV exhibit opposite effect. It was observed, however, that the rupture occurred usually at the thinnest places. Since neither Neale nor Fury give details of the film casting technique, it is difficult to argue this point but it is equally difficult to imagine why a general rule should be applicable in all cases, specially, that varying components themselves at varying degrees of degradation are involved in most cases.

Considering now individual properties of the various mixes, it has been observed that films of mixes II and III are weaker than those of other mixes. This is, in fact, expected as these two mixes, in addition to usual starch based components contain Vinumal. The essential purpose of addition of this emulsion to sizing mixes is to increase their degree of softness, which has rightly been reflected by lower breaking strengths and higher ultimate elongations of their films. The degree to which emulsion will impart softness to a size mix will depend, besides other factors, on its plasticiser content.

Before discussing the behaviour of other mixes, it will be worthwhile to survey one of the most important properties of a size film known as associative bonding. This exists between the molecules of the constituent products within a film and affects such properties as internal strength, water solubility, adhesion of the coating to various surfaces, plasticity etc. It has been shown that rapidly dried films are more water soluble than slowly dried films, simply because molecules have not had sufficient time to associate.[77]

When associative bonding between starch molecules is low, it might be expected that the dried film will have lower tensile strength and higher plasticity than a highly organised film. Very few investigators have attempted to study bonding within a dried size film. One of the more pertinent investigations is that of Bradbury[78] who evaluated associative bonding in textile warp sizing by measurement of the rate of solubilisation of the starch by enzyme. Hull and Schoch,[79] with the advent of many new types of starch modifications, developed a method for evaluating both the extent and the strength of associative bonding within a starch film. They found that cold water solubility of the dried film provides a satisfactory criterion of the extent of molecular association within the film. Thus a film in which molecules are completely dissociated will be entirely soluble in cold water. If any of the starch substance is associated, then material will be insoluble in water. Strength of this associative bonding is evaluated by determining the solubility in water at elevated temperatures, which disaggregates the more weakly associated starch.

The above study offers an explanation for the greater tensile strength of native starches. For example, films of thick boiling corn starch are found[79] to show less solubility as compared with thin boiling corn starches. This low solubility of thick-boiling corn starch at all extraction temperatures has been attributed principally to the persistance of micellar structure in the starch film.

The lower tensile strength values obtained in the present study for films of different sizing mixes (composed mainly of modified starches) appear to be due to high solubility of the various constituent products (Fig. 14). This property is reflected in the pattern of the final film.

It is seen from the results (Table X) that films made out of mix I give the value for tensile strength which is considerably lower than those obtained with other mixes (except mixes II and III which contain

Vinamul), in spite of the lower solubilities of its component products. Thus an explanation based on the solubility of the products fails to account for the behaviour of these films. But one of the components of mix I is Solvitose HCT_1 which is etherified potato starch. This Solvitose, like its parent substance, swells to a considerable extent even at low temperatures. Thus it may be presumed that this component is not a highly modified product. Potato starch itself yields very highly soluble films because its linear fraction is much less prone to retrograde or gel due to some obscure differences in molecular structure which are not yet understood.[78] Following this behaviour of potato starch, it appears that Solvitose HCT_1, being only slightly modified itself, is mainly responsible for the lower tensile strength of films of mix I.

Finally, for films of mix VI, it might be expected to obtain lower tensile strength values because of its Vinamul content. Further, Chieftain, another component of the mix is highly soluble (Fig. 14) which should lead to weaker films. This, however, is not true - the films have high tensile strength and therefore it appears that the remaining component of the mix, i.e., sago starch, which does not go into solution to an appreciable extent even at high temperatures, is solely responsible for the improved performance.

The above remarks could be further corroborated by film casting and testing the different components of the mixes in isolation but, since the main purpose of the work was to establish relations between compound mix films and their value as back-sizing agents, this possibly interesting side line investigation had to be regretfully abandoned.

4.22 - Bending Length and Flexural Rigidity

Usually differences of 10 percent. in the values are considered as significant and representative of an appreciable difference in handle, and the small variations found in this case can be probably discounted. Nevertheless, the values are given to three figures.

A different situation exists with regard to flexural rigidity as it is highly dependent on the thickness of the specimen. It takes greater force to bend a thick strip than a thin one, and in fact doubling the thickness increases the flexural rigidity eight fold.[62] Thus for any comparison between these properties, thickness will always have to be taken into consideration. This fact accounts for the large differences observed in the values for flexural rigidity for three different concentrations of the same sizing mix.

Considering mixes II, III and VI, all containing Vinamul, it was seen that values for c and G are much lower for mixes II and III, whereas these values for mix VI compare well with those of other mixes which do not incorporate in them Vinamul emulsion. Also the plasticiser content of Vinamul N 8120 used in mix VI is 20% as compared with 14% of Vinamul N 8114 employed for mixes II and III. It might, therefore, be expected that films of mix VI should be much less stiff. This expectation could have been valid if other components of these mixes were exactly the same. Examining components of these mixes, it appears that sago starch (native kind) is probably responsible for making films of mix VI stiffer, since other components are all modified products. Further support to this effect is also obtained from the values of tensile strength and extensibility tests (Table X) where films of mixes II and III are shown to be softer than those of mix VI.

In general, it is found that values obtained for c and G for films of different sizing mixes go hand in hand with their values for tensile strengths and extensibility. Thus films having high values of c and G also result in high tensile strength values and vice versa. This, therefore, confirms the view that the same elastic property of the material is involved in bending as in stretching.[80] Pierce[56] provided evidence to support this view on the basis of the values for Young's modulus calculated from bending experiments and found that they were the same as those obtained by Neale[53] in tensile tests.

4.23 - Flexing Strength

Tensile strength and stretch of size films is not the only criterion of their excellence and the only guide to their application for various processes. Practically all fabrics of a mechanical nature, to which size is applied, are subjected to fluctuation and repetition in stress. This, therefore, calls for toughness, rather than shear strength.

Fury,[58] while determining the folding endurance of size films on an instrument patterned after Massachusetts Institute of Technology paper folder tester,[81] found that folding endurance of films of all starches decreased as their thicknesses increased. Further, on plotting values for folding endurance for film strips against their corresponding thicknesses, he found that the relationship between two variables was curvilinear for most of the starches. The results obtained in the present work for flexing strength of films of different sizing mixes appear to be in accordance with those observed by Fury. However, he did not put forward any explanation for variation of folding endurance of films with their thicknesses. A possible explanation to this effect can be put forward as under:

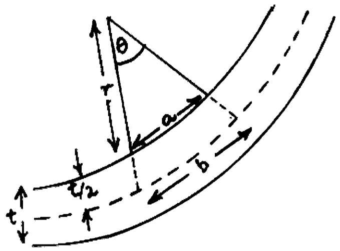


Fig. 35.

Consider a film strip of thickness 't' which bends so that the radius of curvature is 'r'. Bending involves compressive forces on the inside of the bend [82,83] and tension forces on the outside. If 'θ' is the angle of bending, and neutral axis (centre line of film strip shown in dotted line) of the film specimen is considered, then

$$a = r\theta$$

$$\text{and} \quad b = \left(r + \frac{t}{2}\right)\theta$$

It follows, therefore, that strain $= \dfrac{b - a}{a}$

$$= \frac{\left(r + \frac{t}{2}\right)\theta - r\theta}{r\theta}$$

$$= \frac{\frac{t}{2}}{r}$$

Thus with greater thickness of the film, higher strain will be set up leading to its rupture much easier than with thin film for which strain will be of lower order; magnitude of stress being the same in both cases.

Now, it was established by experimental observations that as the weight of film strip increased, number of flexes required to rupture it decreased. If it is assumed that weight of the film strip is proportional to its thickness, then the above theoretical consideration accounts well for experimental observations.

It might be expected that films of high tensile strength will give a high value for flexing strength. Thomson and Traill[84] while discussing the importance of resistance of fibres to repetitive bending stated that some modern rayons with tensile strength of 60 to 120 kg./mm. broke with great ease, whilst other fibres with higher strengths did not show such brittleness. It follows that the ability to withstand repetitive bending depends not on the tensile strength of material but on its compressional and tensional repeated stress properties. This helps to explain the greater flexing strengths of films of mixes II and III as compared with those of some other formulations, in spite of low tensile strength values for these two mixes.

All the film specimens broke at the edge of the clamp for holding films, as would be expected, but since this was the part of maximum flexure, the results may not have been in error.

4.3 - TUFT ANCHORAGE AND STIFFNESS PROPERTIES OF LOOM-STATE CARPETS

Comparing the tuft bind of various loom-state carpets (Table XIV) it is seen that there are two major factors determining the strength of tuft anchorage: (a) The type of interlacing, and (b) The density of the cloth. The former is evidenced from anchorage values of sample G against all others - this sample though of medium quality shows best values due to its superior Corinthian construction. The latter factor consists of more complex aspects. the chief among which are density of tuft population per given area, thickness of yarns, class of material, crimp and length of pile. In addition to the influence of each single aspect of this conception of density, there exists an interplay of these various aspects or agencies which even further complicates the picture. It appears, however, that density of loop population is a major factor and this is shown by samples A and E which give superior tuft anchorage and have a considerably greater number of tufts per sq. in. than the samples B, C, D or F. These four samples represent the lower end of quality scale and it appears that at this point the crimp and the thickness of ground yarns may play a more dominant role since tuft withdrawal force for the above four samples cannot be placed in the same order of their densities of loop population.

Considering the stiffness of unfinished carpets, it was seen that the factors were primarily the intrinsic stiffness of the various warp yarns (especially the stuffer) and the thickness and density of spacing of the weft yarns.

4.4 - MECHANISM OF SIZE UP-TAKE

Before the changes produced in tuftbind and stiffness characteristics of various carpet samples by back-sizing process are discussed, it will be worthwhile to consider here the mechanism of size up-take by carpets.

Size pastes are taken by carpets in three different ways: (1) by penetration into yarns, (2) by penetration into fabric interstices, and (3) by surface coating.

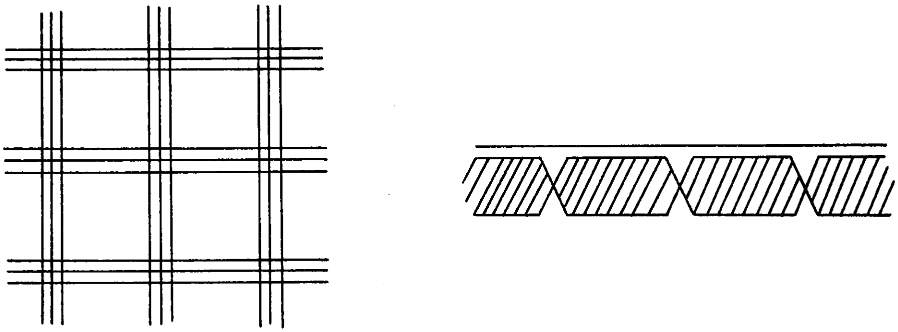
(1) Penetration into yarns (both backing and pile) depends on various factors chief among which are the type, twist, count and imbibition of yarns; kind of size

and rate of passage through sizebox. Besides, penetration also depends on the viscosity of size paste and surface tension between fibres and size mix. It has been shown that penetration in this case varies directly as the fluidity and inversely as surface tension.[85]

Of the two sets of yarns it is considered that backing yarns will be responsible for the bulk of size absorbed and pile yarns will account for only a small proportion of it. This is due to the fact that pile yarns are: (a) inaccessible to size except for the small area woven into the backing, (b) this small area is further partially obscured by backing yarns, and (c) even the exposed portion of the yarn is some distance away from the point of size application.

(2) Penetration of size into fabric interstices depends on the density of the construction itself. In common with other woven structures carpets in plan view form a sieve or screen (Fig. 36A) effect with high density areas at yarn interlacing points, and low density areas, or interstices between the interlacing points. These interstices provide convenient sites for size penetration. From the point of view of profile characteristics of the fabric, another aspect is also important, which is

peculiar to spool Axminster carpets. In this construction, ridges are formed at the points where chain warps cross each other between the shots of the weft (Fig. 36B), and since no dead yarn is employed for the purpose of supporting tufts, empty spaces are available at these sites which can be and are filled with size. It is obvious that the more open the setting, the greater the scope for this type of penetration always, provided viscosity and adhesive power of the paste is sufficient to take advantage of the opportunities provided by the construction.



A. Schematic Plan View - "Sieve Effect"

B. Schematic Profile - "Ridge" or "Furrow Effect"

Fig. 36.

(3) Any excess amount of size taken up during sizing process by carpets and which is not governed by either (1) or (2) is just in the form of surface deposition or film on the back of the carpets. This surface coating is

mainly caused by very viscous pastes which do not easily penetrate into the fabric structure or by highly set fabrics which resist penetration by their high density. This excess size is partly removed by passing the cloth over a doctor blade fitted near the edge of the size trough. In some cases, a back brush is preferred which probably removes the excess more effectively and in addition help to brush the size in.

It is important to realise that the place for the back-sizing agents is inside the backing, not on it. Resistance to penetration can be produced by the oil in the jute weft, by the yarn twist, by close shotting in some cases or by hydrophobic nature of certain fibres, therefore, before the sized carpets are finally dried, it is essential that there should be a soaking period to ensure that adequate time is given for the size to penetrate. To achieve this, usually sized carpets are led for a certain distance over a system of rollers before drying begins. One drawback of this method is that the cloth arrives at the drying zone colder than it would otherwise be so that start of drying is retarded. In order to overcome this drawback, the use of a hot plate to initiate drying is often advocated, specially for cylinder driers. This, in theory, will stimulate penetration by rise of temperature and has the advantage that the cloth then goes to the cylinder with drying virtually begun. So far as chamber driers are concerned, the question of cloth temperature on entering the drier is not of such great importance, since drying is done not by contact with heated surface, but by passage through a heated chamber.

The usefulness of any size mix cannot be truly evaluated if resistance to wear is not taken into account. This aspect from the point of view of both the customer and the manufacturer is most important, since it is known that a considerable amount of size powders-off even during storage and transportation. Therefore the changes produced in the characteristics of sized carpets immediately after sizing may not represent a true criterion.

With regard to resistance to wear, it can be easily conceived that the size which penetrates into yarns, offers the maximum resistance and, therefore, helps to produce a more lasting effect. The resistance to wear of a sized material in which the size goes into the interstices of a fabric, will probably depend on the toughness and adhesive power of a size film. The least resistance to wear will naturally be offered by the size film which remains on the surface of the backing. The effect produced by this surface coating may be almost completely lost by simple rubbing or scraping action, unless the coating possesses an exceptionally high tenacity of film as is, for instance, exhibited by rubber latices.

4.5 - EFFECT OF SIZE ON TUFT ANCHORAGE AND CARPET STIFFNESS

The extent of improvement in tuft anchorage is found to depend largely, but not entirely, on the amount of size applied. The reasons for the differential uptake of size have been adequately discussed in the preceding section, therefore, in this section only comments on effects of the variations are appropriate.

Considering mixes I and VII, which have the highest and lowest viscosity values respectively, at any particular rate of shear and temperature, it is seen that mix VII is taken up by various carpet specimens to a much greater extent. Furthermore, this mix also contains the highest amount of solids in the paste and from the data for size pick-up by carpet samples, it is observed that this mix is taken by all carpets, except sample E, to the maximum extent. The exceptional behaviour of sample E is explained by the fact that it is a construction of highest density, exceeding in this respect even sample A which otherwise has the same tuft population. This illustrates the fact that structures of extremely compact nature may require special size formulations in order to benefit from the process. Figure 33 demonstrates that maximum gain in tuft withdrawal force is also obtained with mix VII in all carpet specimens except E.

After mix VII, the next in line as regards the amount of size taken by various carpet specimens is mix IV, though this mix is of higher viscosity as compared to mixes V and VI. This observation could be explained by the fact that the components of mix IV (i.e. Solvitose CG and T-Gum) are much more soluble than those of mixes V and VI and that its solids content is also higher. Again, as was observed with mix VII, sample E shows irregular behaviour further corroborating the reasons advanced above. The relation between solids in the paste and gain in tuft withdrawal force is set out in Fig. 34. This suggests the importance of using highly modified products in the size mix. The lower viscosities of the modified forms render possible the use of the larger quantities of solids in the size mix without increasing the viscosity beyond working limits. Viscosity requirements will, however, vary with the structure and composition of carpet specimens. For example, with sample D which has a very open backing, pronounced wicking up of size is noted with mixes of low viscosity.

In order to study the effect of construction variables carpets were carefully grouped in such a manner that only the variables under consideration differed, other details remaining identical. This precaution was necessary due to considerable variability of structural details in the carpet samples available. From the point of view of control of sizing conditions it was found necessary to reduce the speed of the applicator roller for all samples containing Fibro yarns in the backing. The reduction from 90 r.p.m. to 30 r.p.m. seemed to compensate adequately for the higher imbibition property of Fibro warp yarns. This type of adjustment is in conformity with the standard industrial practice.

For the study of the effect of density of pile on the tuft withdrawal force of sized carpets, comparison is made between the following two pairs:

(1) Sample A against B
(2) Sample C against D

As is to be expected, greater gain in tuft bind is obtained with samples having lower pile density. The reasons are explained in the study of the mechanism of size up-take (section 4.4) and it is obvious that with more open structure, size mix has a better chance to penetrate towards the base of the tufts and spot weld them with the ground structure thus resulting in greater tuft bind. The only divergance from this role occurs between samples C and D with mix I. This very viscous mix is unable to penetrate freely and, therefore, it is thought that with this type of formulation the intrinsic tuft anchorage value will not be so readily marked especially with low qualities where degree of penetration is essential to secure good binding properties.

As regards the effect of different backing materials on tuft anchorage of sized carpets, sample B was compared against sample D. While these samples have different backing yarns, pile density is comparable. It is regarded that difference in pile yarn characteristics produce insignificant changes and this variable is discounted for comparison purposes.

On comparison of the above two sample it becomes obvious that sample D shows in all cases a considerably greater percentage increase in tuft withdrawal force with all mixes (Tables XV - XX). This suggests that the viscose rayon yarns incorporated in the backing of this sample enable the size to penetrate further towards the surface which action achieves better cementation of pile yarns to the ground construction. This deduction becomes particularly valid since the amount of pick-up appears comparable with most mixes. The improvement is very noticeable and values for sample D equal, and in one case better, the sheer numerical values of tuft anchorage of sample B, even though the former only shows 60% strength of the latter in unfinished state.

Considering the effect of size on stiffness of carpets it can be observed that original rigidity values are almost completely submerged and entirely new stiffness characteristics are formed. The general tendency of high size up-take by low quality carpets produces an effect of vastly improved rigidity which in many cases exceeds the rigidity value of higher quality samples (Tables XXVIII to XXXIII). As before, the greatest increases are observed for mix VII which is followed by mix IV. This again confirms the usefulness of highly degraded products. In connection with the amount of size up-take, it can be stated that this, though of some importance, is not the preponderant factor. In fact, some cases exhibit (in the same sample) equally good or better stiffness with half the weight of the solids per sq.yd. (e.g. sample D - mixes III and VII, sample A - mixes I and VI, and many others). Generally it could be said that the main criterion will be, neither the initial stiffness, nor the intrinsic characteristics of the mix, but the location of size in the construction. The superior values of low quality, Fibro backed samples seem to suggest that the location within the warp yarns and between the ridges of weft will have greatest influence.

4.6 - RESISTANCE TO WEAR OF SIZED CARPET BACKINGS

It was observed from the results for tuft anchorage prior to wear that maximum improvement in tuft bind occurred with mix VII followed by mix IV. Study of summary table XXVII reveals that even after subjecting the sized carpet backing to wear treatment this order is retained. Thus it appears that though enormous amounts of solids are taken up from these mixes by various carpet specimens, they have been accommodated inside the carpet backing with probably very little surface deposition. This observation lends further support to the importance of using back-sizing agents with considerable degree of degradation, so that greater amount of solids could be employed in the formulation of size mixes without causing an appreciable increase in viscosity.

It is of interest to study the resistance to wear of various carpet samples sized with mix VI in which native starch (sago) has been incorporated. From the results (Table XXVII), it is seen that, with this mix, higher percentage decrease in tuft withdrawal force is obtained after wear, especially with samples A and B which contain cotton and linen yarns in the backing. This is consistent with the well known fact that native starches have tendency to powder-off on wear.

Considering carpet samples in pairs, as postulated in previous section to study the effect of certain variables in carpet structures, it will appear from the results that those samples which have lower pile density show better tuft bind even after wear. Thus, it can be concluded that even after prolonged wear, contribution of the back-sizing process is greater towards lower quality carpets.

It is interesting to observe from the results prior to wear that with mixes III and V, those carpet samples which have Fibro yarn in the backing show greater improvement in tuft bind. This effect is attributed to better penetration of Solvitose SN (component of these mixes) into the Fibro yarns. Further support for this explanation is obtained from the results of tuft anchorage tests after wear (Tables XXII and XXIV) which also indicate that carpet samples containing Fibro yarns in the backing and sized with mixes III and V are more resistant to wear than samples containing cotton and linen yarns in the backing. This point again directs attention to a necessity for careful formulation of recipes for a particular set of circumstances.

Finally, it is significant to note that, even after wear action, all sized carpet samples show better tuft anchorage than loom state samples. The same cannot be said with regard to stiffness characteristics and it can be seen in studying tables XXXIII to XXXIX that with some size mixes the rigidity values after wear occasionally fall below the rigidity value for unsized specimens. This suggests that when the size is removed from locations contributing most to improvements in rigidity, it will still remain in locations where it assists in maintaining the improved tuft anchorage.

This again confirms the view substantiated in several previous instances of the necessity of "penetration in depth" to achieve correct and durable tuft anchorage.

Studying the stiffness characteristics after wear, further, it is observed again that mix VII gives best results and mix IV, as before, stands next in order of excellence. Mix VI provides repeated evidence of the vulnerability of native starches to dusting out, great losses being experienced with all samples, whilst in some cases the values fall below the original figures suggesting that dusting-out occurred to such an extent as to expose to wear the backing yarns. Mixes III and V again provide evidence for particular affinity of viscose rayon yarns for Solvitose SN. It is seen that for similar density of construction only Fibro backed samples show improvement of any amount but carpets with cotton and linen backing yarns exhibit a minus value compared with the original. Mix I gives results consistent with its high viscosity i.e. appreciable improvement prior to wear but very severe losses after wear. This is in conformity with the tendency of high viscosity mixes to produce surface deposits rather than agglomerate within the construction.

4.7 - RELATIONS BETWEEN PROPERTIES OF SIZE FILMS AND THEIR BEHAVIOUR ON SIZED CARPETS

The properties of breaking and flexing strength of dried films of various size mixes were studied in order to try and co-relate these with values for tuft withdrawal force of various sized carpet specimens.

Before an attempt is made to discuss any relationship between properties of dried size films and tuft bind of sized carpets, it is essential to point out the fact that the true value of the size film could be assessed only on the basis of how it would be able to withstand wearing action. This point is important because immediately after sizing, carpets may carry an excess amount of size by way of surface deposition and in this state better co-ordination may exist. Yet establishment of the existence of these relations at that particular stage is worthless since the surface deposits can be expected to disappear even with slight disturbances of the carpet. An effort, therefore, must be made to establish a relationship at a point at which the size within the carpet is in a state resembling little the original smooth film.

Since the tuft retention property of sized carpet specimens after subjecting them to wear in "Tetrapod" machine is considered to depend on both the tensile and flexing strength characteristics of dried size films, an attempt has been made to establish a new method of assessing the "durability" of a size film. In this method both the above parameters have been incorporated since each is a contributory factor in determining usefulness of a size film. The method is based on the use of a simple ratio of number of flexes to tensile strength of films of any particular size mix. Thus, considering the average values for flexing and tensile strength of films of various size mixes, following approximate ratios have been obtained for various mixes:

Mix No.	Flexing strength/Tensile strength
I	310/218 = 1.5
II	720/120 = 6
III	580/150 = 4
IV	1630/278 = 6
V	820/272 = 3
VI	1000/307 = 3

In calculating the above ratios, average values for tensile strength have been taken from table X and values for flexing strength have been determined from Figs. 30 and 31 for the same weight (4×10^{-2} gm.) of film strips of various size mixes. The tensile strength values for films of different mixes have not been adjusted for thickness as it is assumed that the variation in thickness may correspond to the different amounts and uncertain distribution of size paste in the sized fabric. The ratios varying from 1.5 to 6 represent various sizing mixes and form an arbitrary scale.

The above method of approach appears to suggest that films of low tensile strength should not be condemned outright since they might achieve a reasonable "durability" number if they could show good flexing strength. By converse, films of high tensile strength could achieve a good "durability" number only if accompanied by a very high flexing strength. It is realised, of course, that extremely high numbers could be obtained by virtue of abnormally low tensile strengths, but it is logical to think that the inaccuracy of such numbers could be obviated by designating only a certain range as being of "merit" ranking, e.g. 3 to 6. Numbers below and above could then be regarded as poor samples without proper degree of balance in their composition.

Considering now the percentage increases in tuft withdrawal force after wear of various sized carpet specimens (tables XXI - XXVI), it was observed that mix IV caused maximum amount of increase (discarding, of course, mix VII for which film characteristics have not been studied) with all carpet samples. This is in agreement with its "durability" number (6). In general, similar agreement appears to exist with other mixes, particularly with mix III.

It is, perhaps, important at this point to repeat again that there are a number of other properties which will have considerable bearing on effects of sizing. Further, it is not only such factors as penetration, adhesion, etc. of the size alone, but also their interrelation with the cloth and constituent yarn characteristics that will affect the results to a high degree. This, therefore, suggests that the above scheme provides at the moment only a rough guide and various correction factors would need to be applied before a more reliable ranking could be achieved. Such elaboration would require creation of mixes and samples of carefully graded characteristics in order to isolate the required properties and to study each one in turn. The lack of such correction factors may account for some of the differences that have been observed in the process of establishing the postulated relationship. For example, mix V has a better ranking number (3) than mix I (1.5), but consistently smaller increase in tuft bind is shown by the former mix. On the other hand it is feasible that mixes with "merit" ranking of 3 and below are altogether less reliable in performance and the superior effect ranking might be limited to a narrow band of 3.5 to, say, 6.5. In either case, more proof than has been so far provided is necessary.

Considering the rigidity aspect it is known that stiffness is related to the resistance of a fabric to bending, and it is of interest to see how carpet (sized) stiffness is related to the data on flexural rigidity of size films. In the first instance, it should however be pointed out thatthe stiffness of a sized fabric depends on the degree of penetration and coating power of size paste, which in turn will be governed by consistency of the paste.[24, 86] Besides, as previously mentioned, construction of a fabric is also an important factor in evaluating its stiffness especially in connection with the area of location of size within the structure.

Comparison of the values for flexural rigidity of carpet samples sized with various mixes (tables XXXIV - XXXIX) with those of their films (table XII) indicate that no strict co-relation exists between the two.

Probably the study of free films could hardly be expected to give absolute co-relation since the tests on films are made exclusively on the size, without the "re-inforcing" action of yarn or fabric. However, in any future work, if an attempt is made to find such relation with success, the work might need to be confined to variations of one particular size mix in respect of one given quality of carpet.

[illegible] erties of Size Films

[illegible] trength values obtained [illegible] g sizes (composed mainly of modified [illegible] lower than those for native starches. [illegible] has been explained on the basis of [illegible]

[illegible] reason [illegible]

CONCLUSIONS

[illegible]

[illegible] and [illegible]

1) For [illegible] of loom-state carpets, important fact[illegible] are: (a) [illegible] of inter-lacing and (b) The densit[illegible] of cloth. [illegible] example of the first factor is [illegible]

The Physical Properties of Size Films

1) The tensile strength values obtained for films of various sizing mixes (composed mainly of modified starches) are lower than those for native starches. This difference has been explained on the basis of higher solubility of modified starches.
2) In general, addition of Vinumal to size mixes decreases the tensile strength, bending-length and flexural rigidity but increases the flexing strength of their films.
3) Flexing strength of size films decreases as their thickness increases. It has been shown by simple mathematical means that increasing thickness will give rise to higher strain values which in turn would cause the films to rupture much easier.

Tuft Anchorage and Stiffness Characteristics of Unsized and Sized Carpets

1) For tuft bind of loom-state carpets, important factors are: (a) Type of inter-lacing and (b) The density of cloth. An example of the first factor is sample G, which though of medium quality shows best tuft anchorage of all the samples due to its superior Corinthian construction. Samples A and E show

good tuft bind in the loom-state because of their high density of tuft population. For lower quality of carpets, it is suggested that other factors such as crimp and thickness of ground yarns may play a more dominant role.

2) The extent of improvement in tuft anchorage depends largely but not entirely on the amount of size applied. From the various observations made, it is obvious that especial construction conditions will demand careful formulation of size mixes in order to benefit fully from the Back-sizing process. In this connection, a considerable improvement in tuft anchorage is generally encountered with pastes containing high amount of solids. This suggests the usefulness of highly modified products.

3) Greater gain in tuft bind on sizing is obtained with samples having lower pile density. Because of the more open structure of these samples, size mix has a better chance to penetrate towards the base of the tufts and spot weld them with the ground structure. In connection with this effect, it is observed that carpets containing viscose rayon backing yarns exhibit particularly good tuft anchorage on sizing, probably due to good penetration characteristics of these yarns.

4) Important factors which contribute towards the stiffness of loom-state carpets are the intrinsic stiffness of warp yarns (especially the stuffer), thickness and density of spacing of the weft yarns. Regarding the influence of size up-take on the stiffness of carpet samples, it can be stated that this, though of some importance, is not the preponderent factor. It could be said that the main criterion will be neither the initial stiffness nor the intrinsic characteristics of the size mixes but the location of size in the construction. The general tendency of high size up-take by low quality carpets produces an effect of vastly improved stiffness and as a matter of fact in many cases their rigidity values exceed those of high quality carpets.

5) After subjecting sized samples to wear action, high resistance is observed with highly modified products whilst native starch shows a distinct propensity towards powdering off. In general, carpet samples which have low pile density exhibit good tuft bind even after wear. Thus it can be concluded that even after prolonged wear, contribution of Back-sizing process is greater towards lower quality carpets.

Relation between Properties of Size Films and their Behaviour on Sized Carpets

Some evidence has been found to support the view that certain relationship exists between properties of size films and tuft withdrawal force. However, greater volume of proof is required to corroborate the evidence so far obtained. Furthermore, it is suggested that in order to provide a comprehensive answer, it is necessary to work with samples of carpets of sufficiently well defined gradation of structural detail to allow for methodical elimination of variables of construction.

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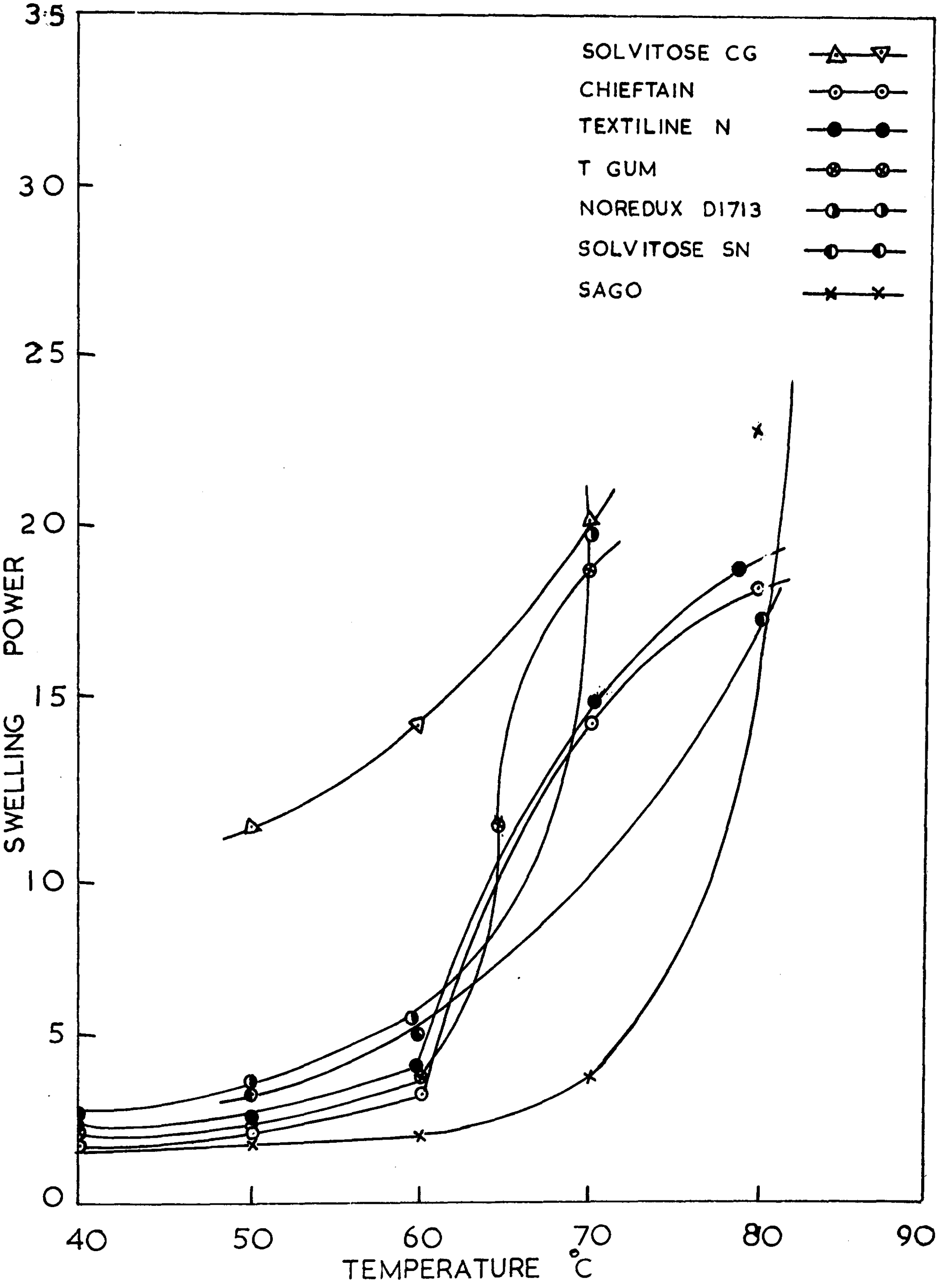

FIG. 13. SWELLING PATTERNS OF VARIOUS SIZING AGENTS.

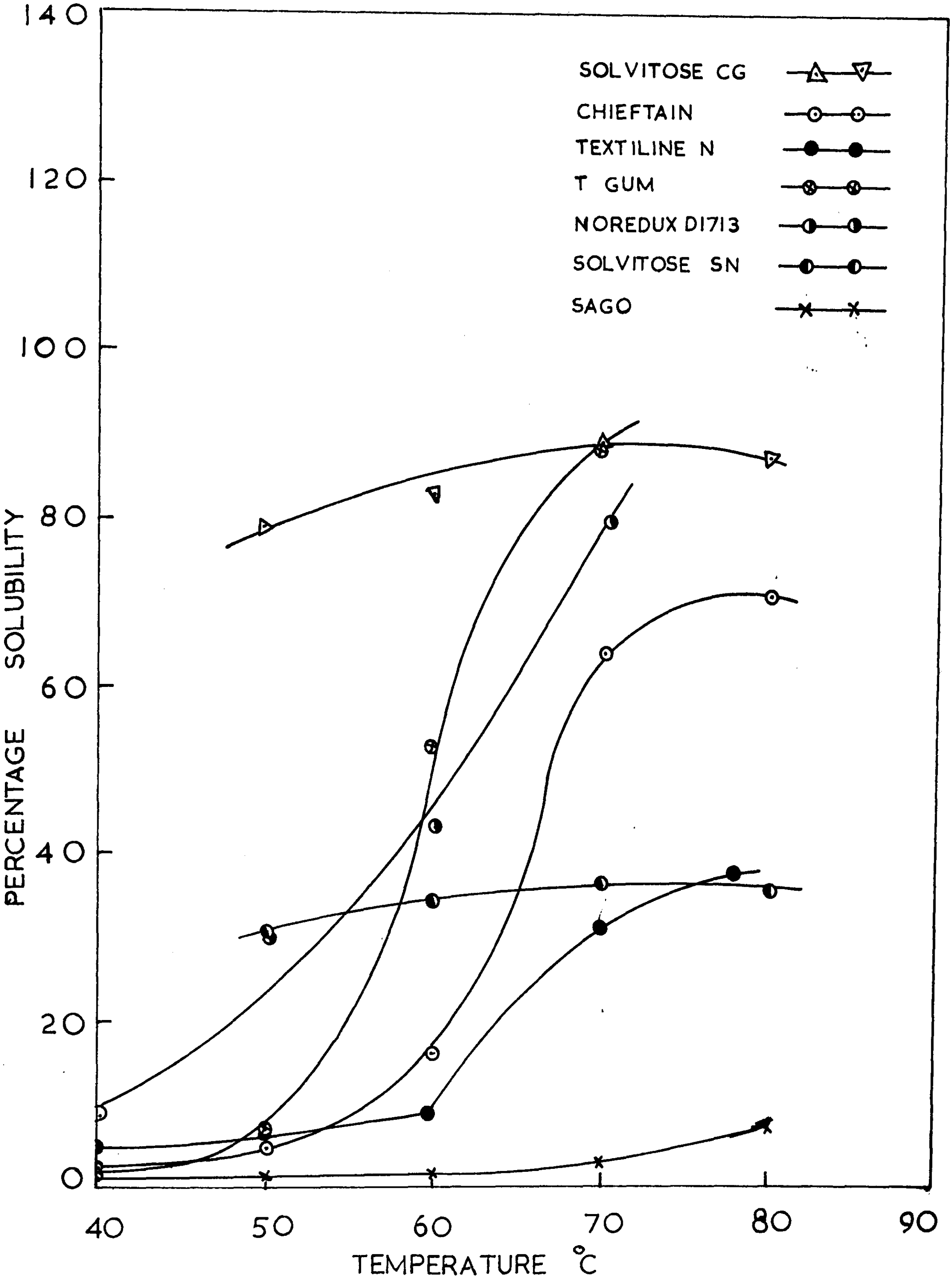

FIG. 14. SOLUBILITY PATTERNS OF VARIOUS SIZING AGENTS.

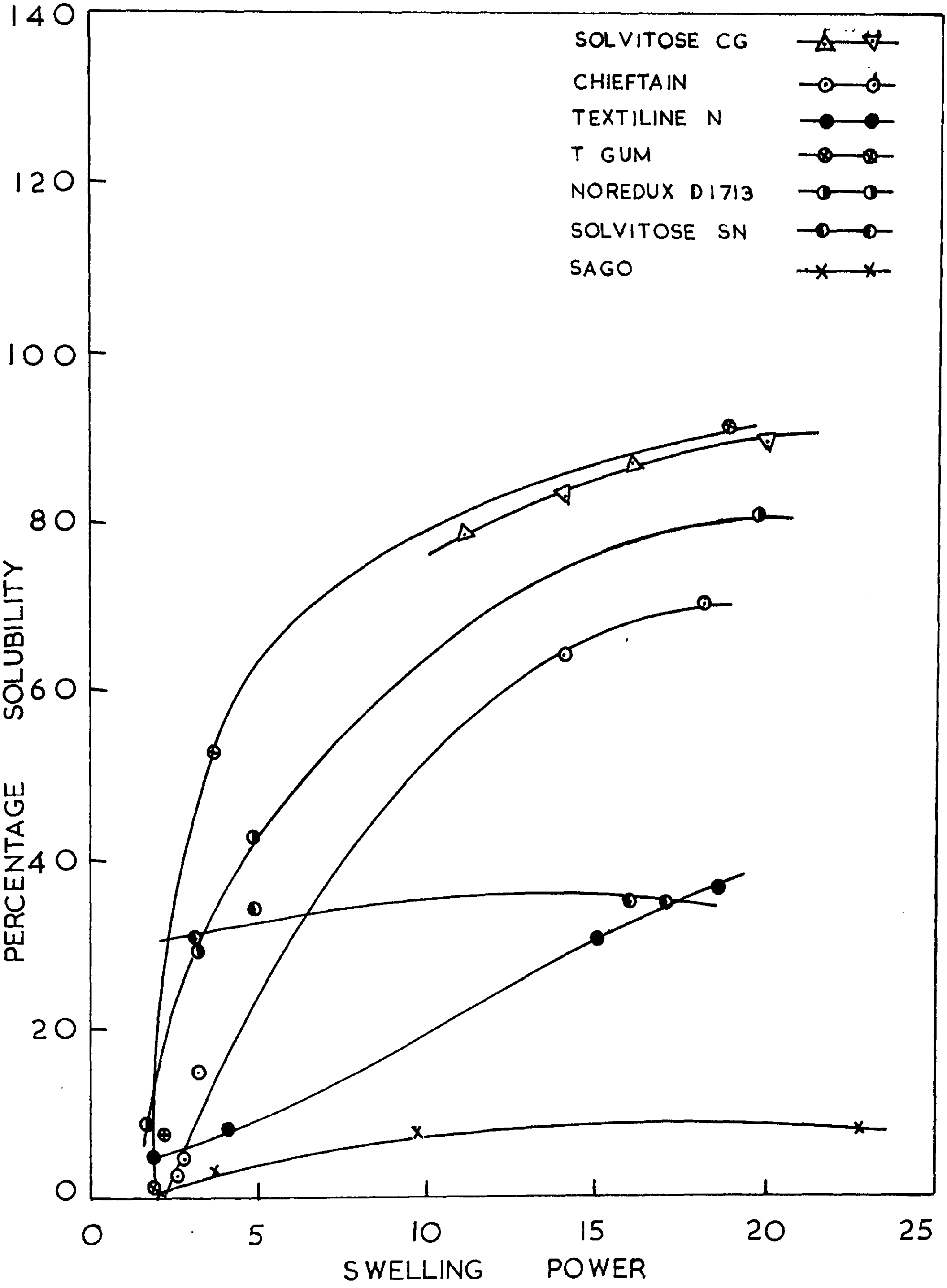

FIG. 15. RELATION BETWEEN SWELLING POWER AND SOLUBILITY OF VARIOUS SIZING AGENTS.

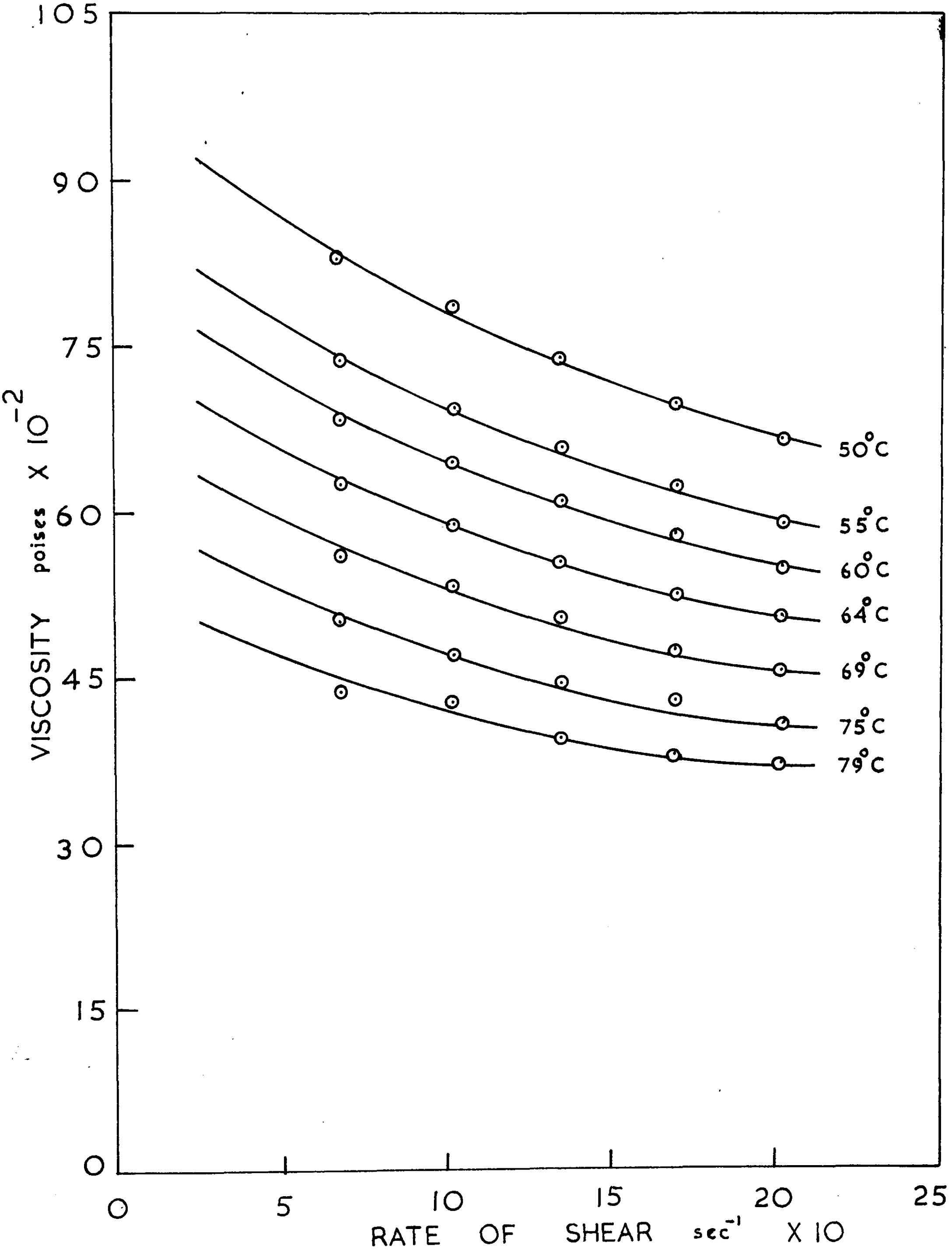

FIG. 16. EFFECT OF RATE OF SHEAR ON THE VISCOSITY OF SIZE MIX II THROUGH A CYCLE OF TEMPERATURE CHANGES.

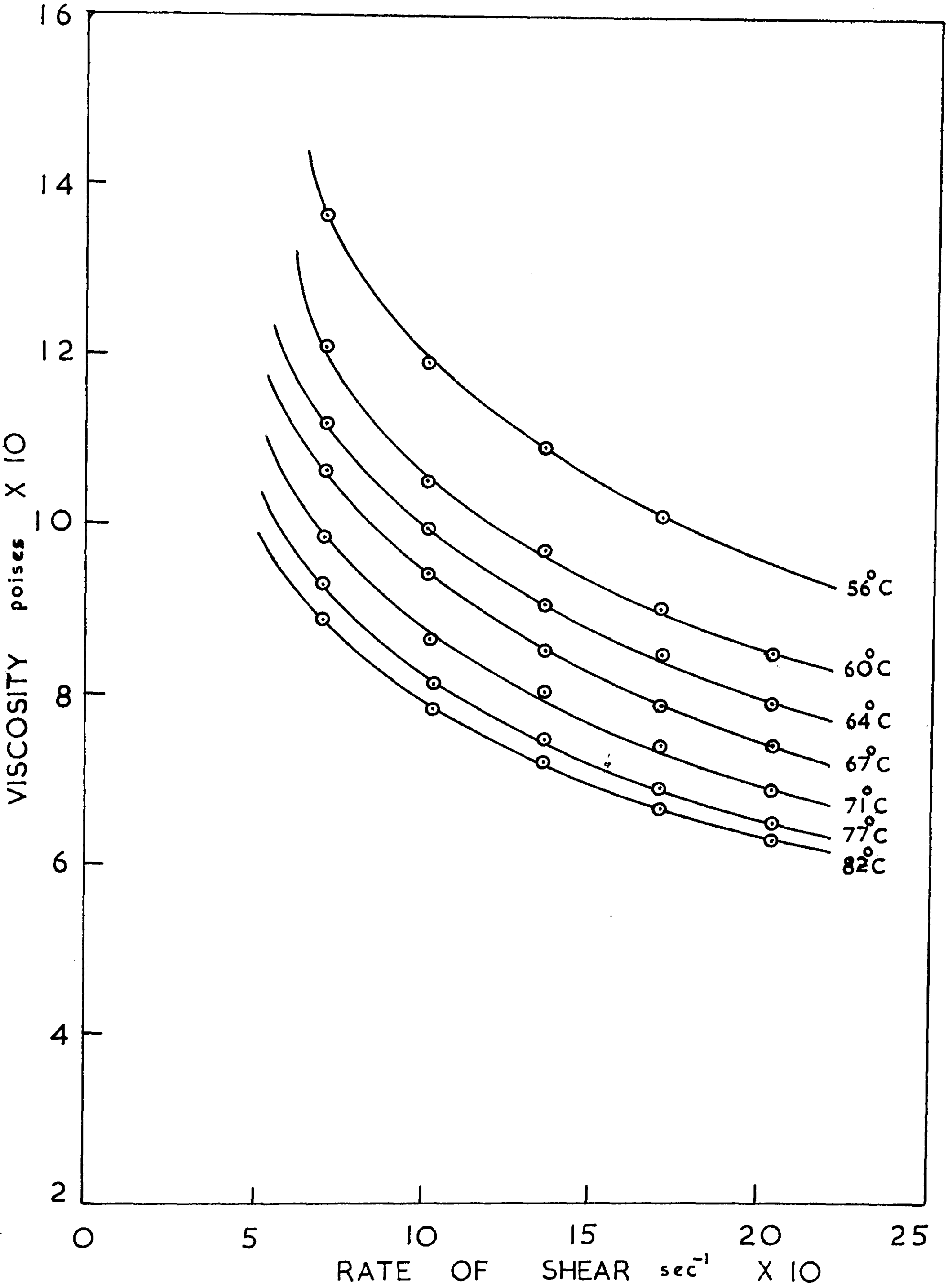

FIG. 17. EFFECT OF RATE OF SHEAR ON THE VISCOSITY OF SIZE MIX III THROUGH A CYCLE OF TEMPERATURE CHANGES.

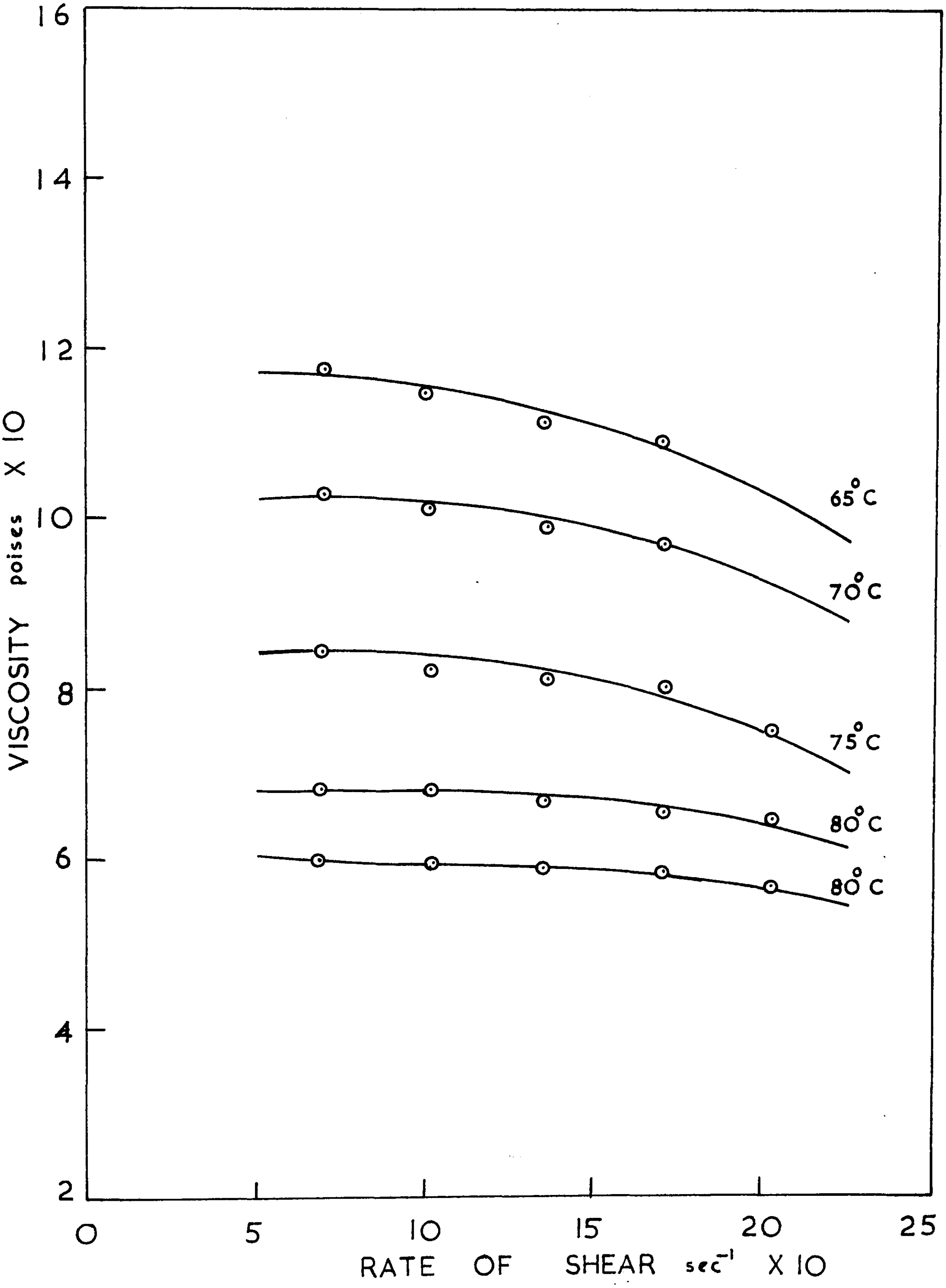

FIG. 18. EFFECT OF RATE OF SHEAR ON THE VISCOSITY OF SIZE MIX IV THROUGH A CYCLE OF TEMPERATURE CHANGES.

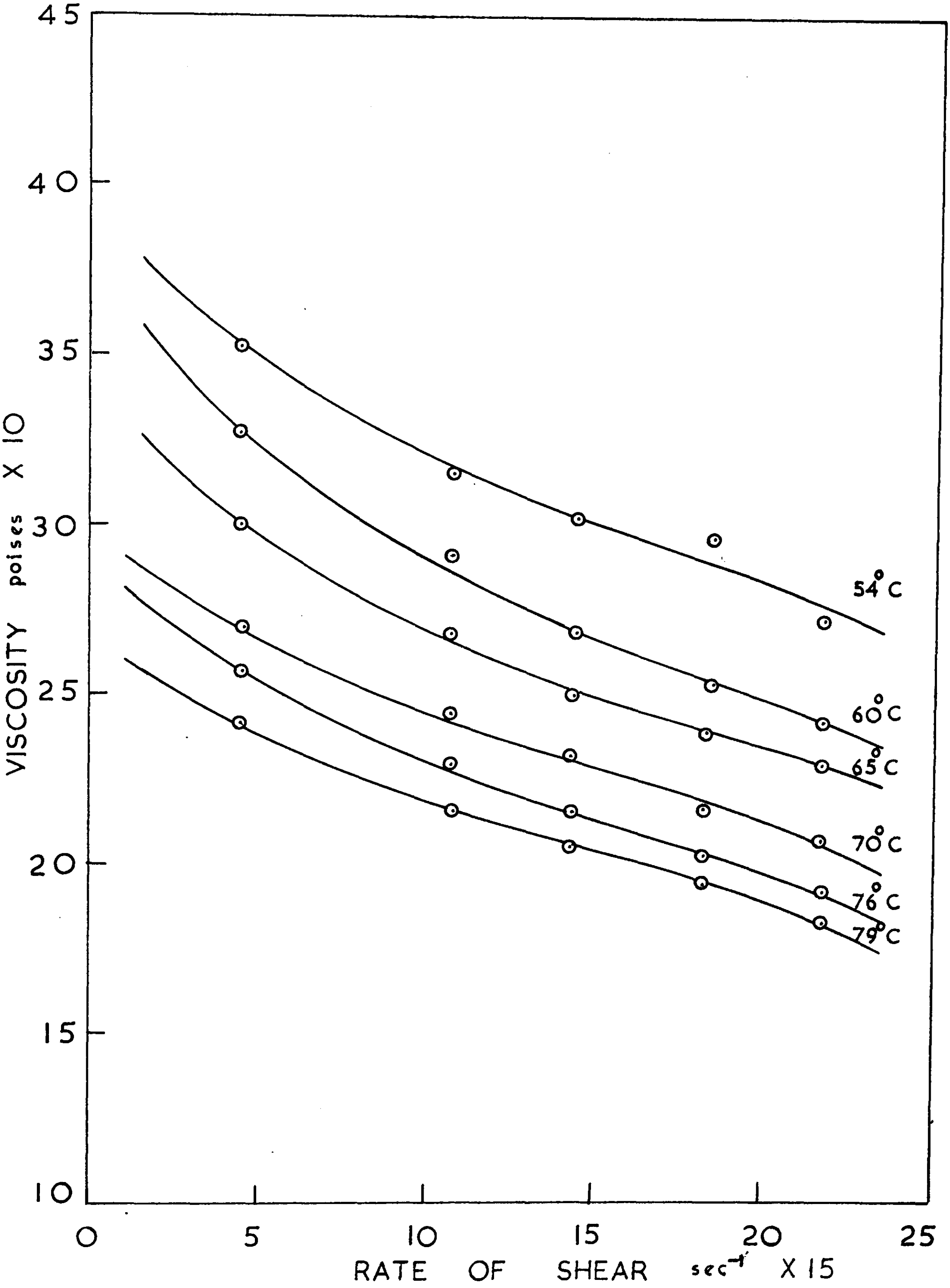

FIG. 19. EFFECT OF RATE OF SHEAR ON THE VISCOSITY OF SIZE MIX V THROUGH A CYCLE OF TEMPERATURE CHANGES.

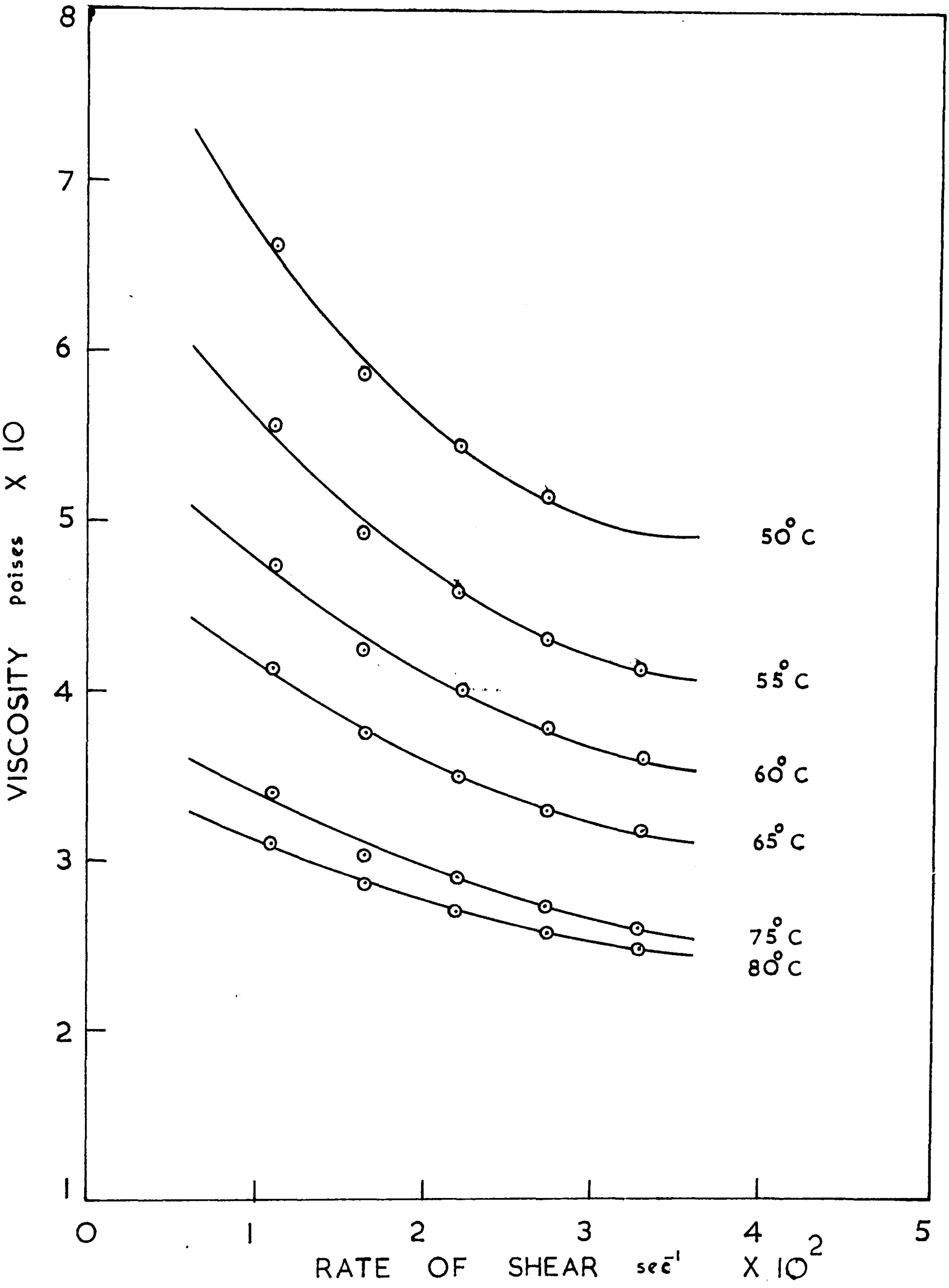

FIG. 20. EFFECT OF RATE OF SHEAR ON THE VISCOSITY OF SIZE MIX VI THROUGH A CYCLE OF TEMPERATURE CHANGES.

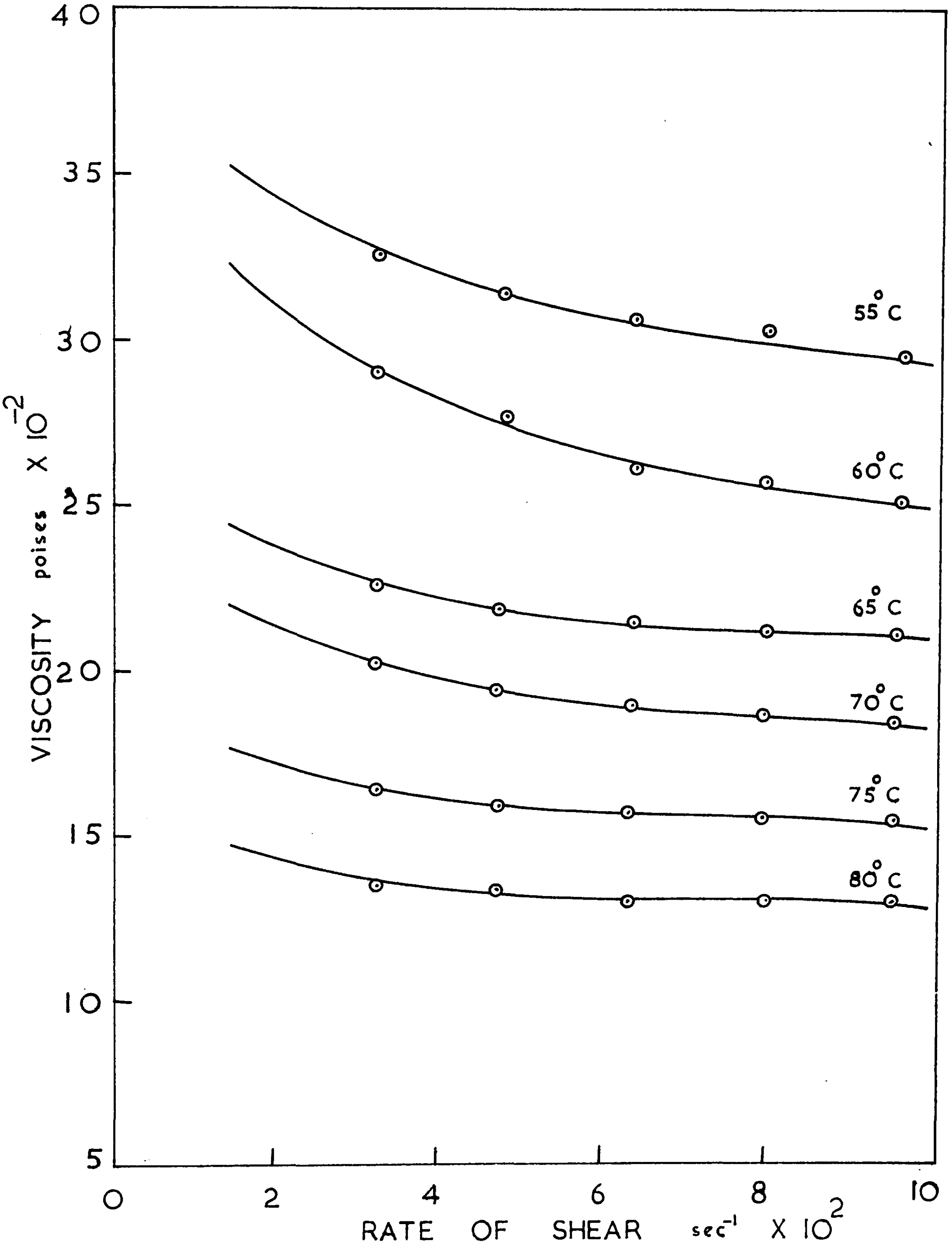

FIG. 21. EFFECT OF RATE OF SHEAR ON THE VISCOSITY OF SIZE MIX VII THROUGH A CYCLE OF TEMPERATURE CHANGES.

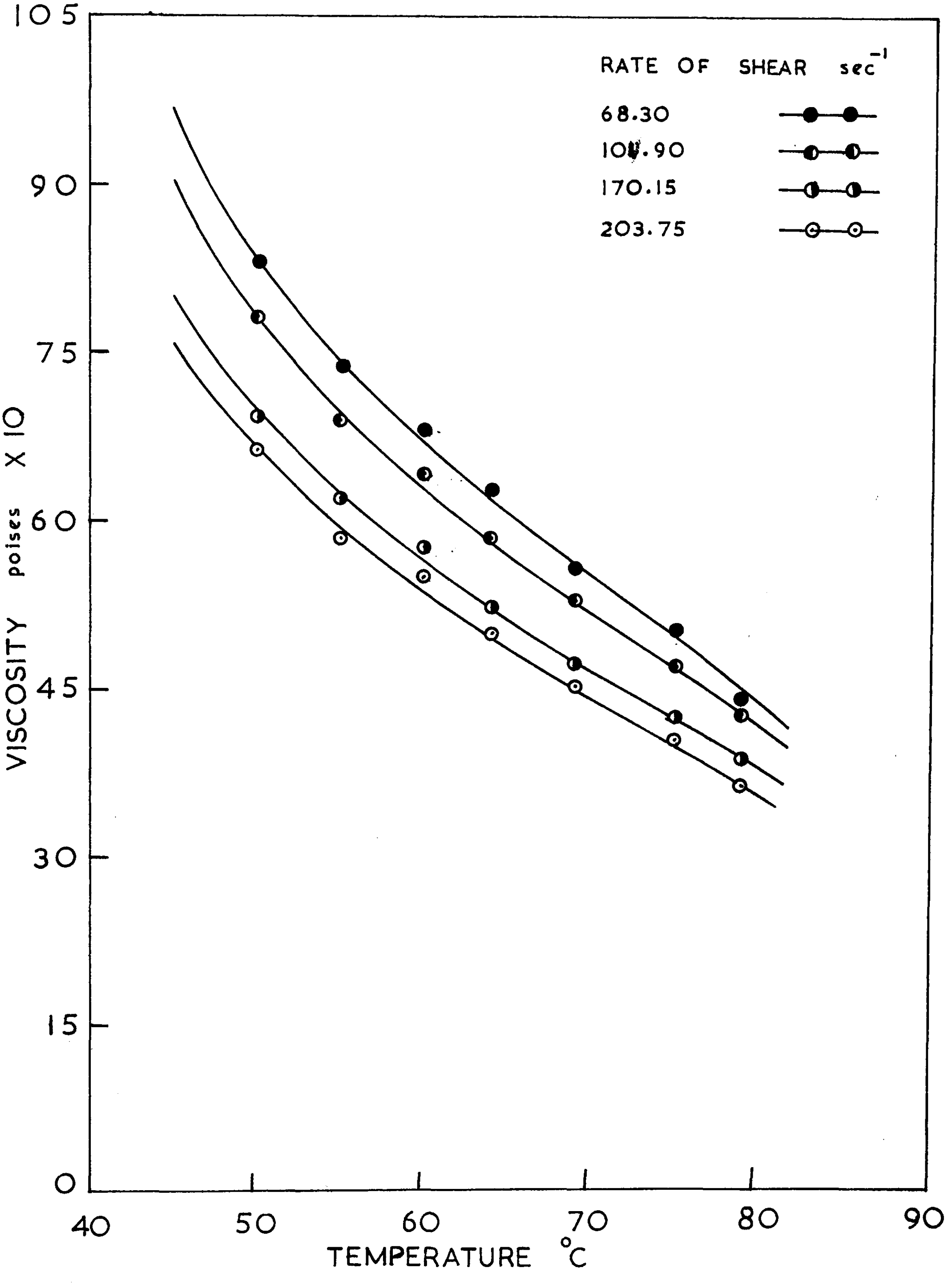

FIG. 22. EFFECT OF TEMPERATURE ON THE VISCOSITY OF SIZE MIX II AT VARIOUS RATES OF SHEAR.

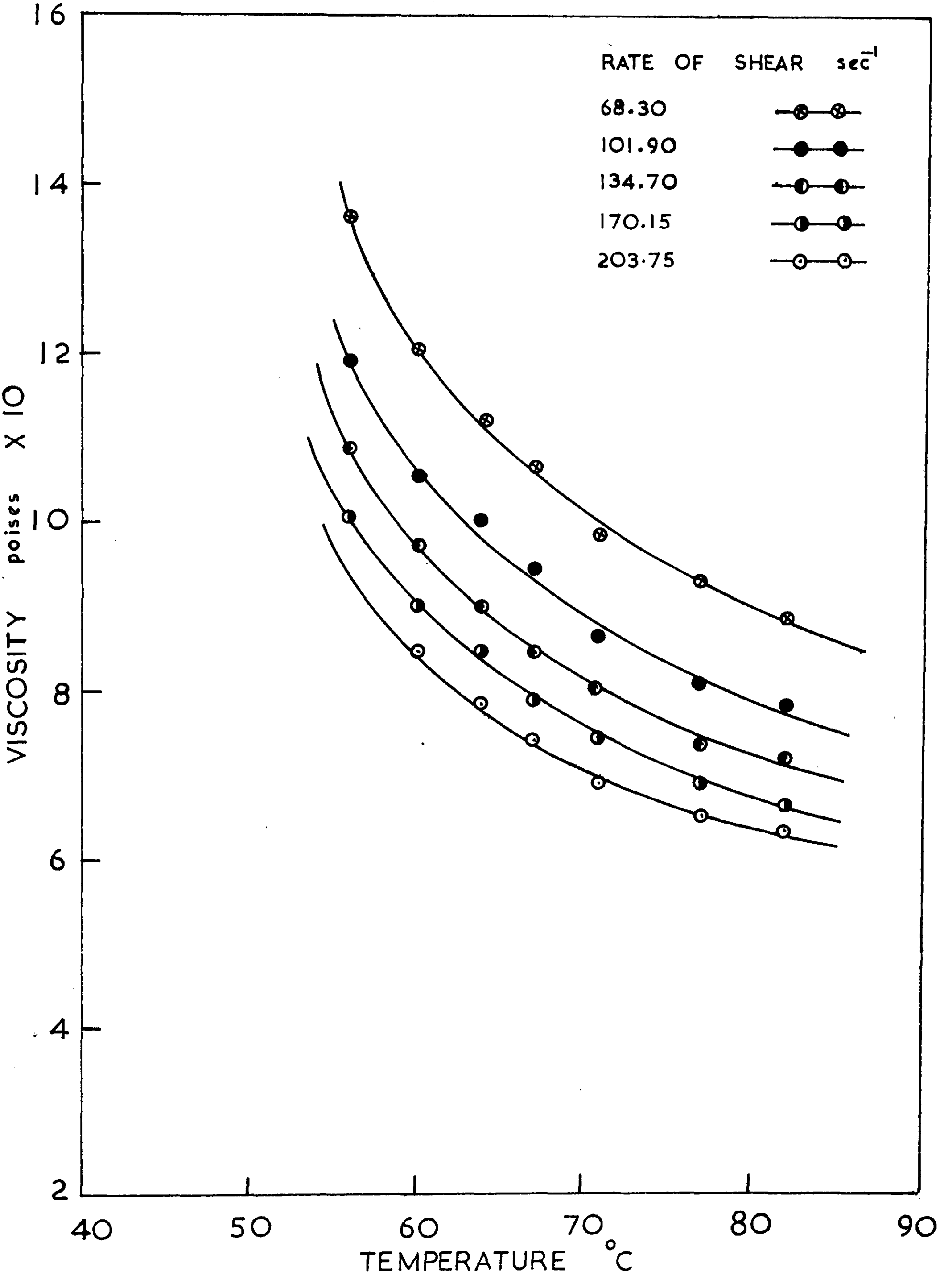

FIG. 23. EFFECT OF TEMPERATURE ON THE VISCOSITY OF SIZE MIX III AT VARIOUS RATES OF SHEAR.

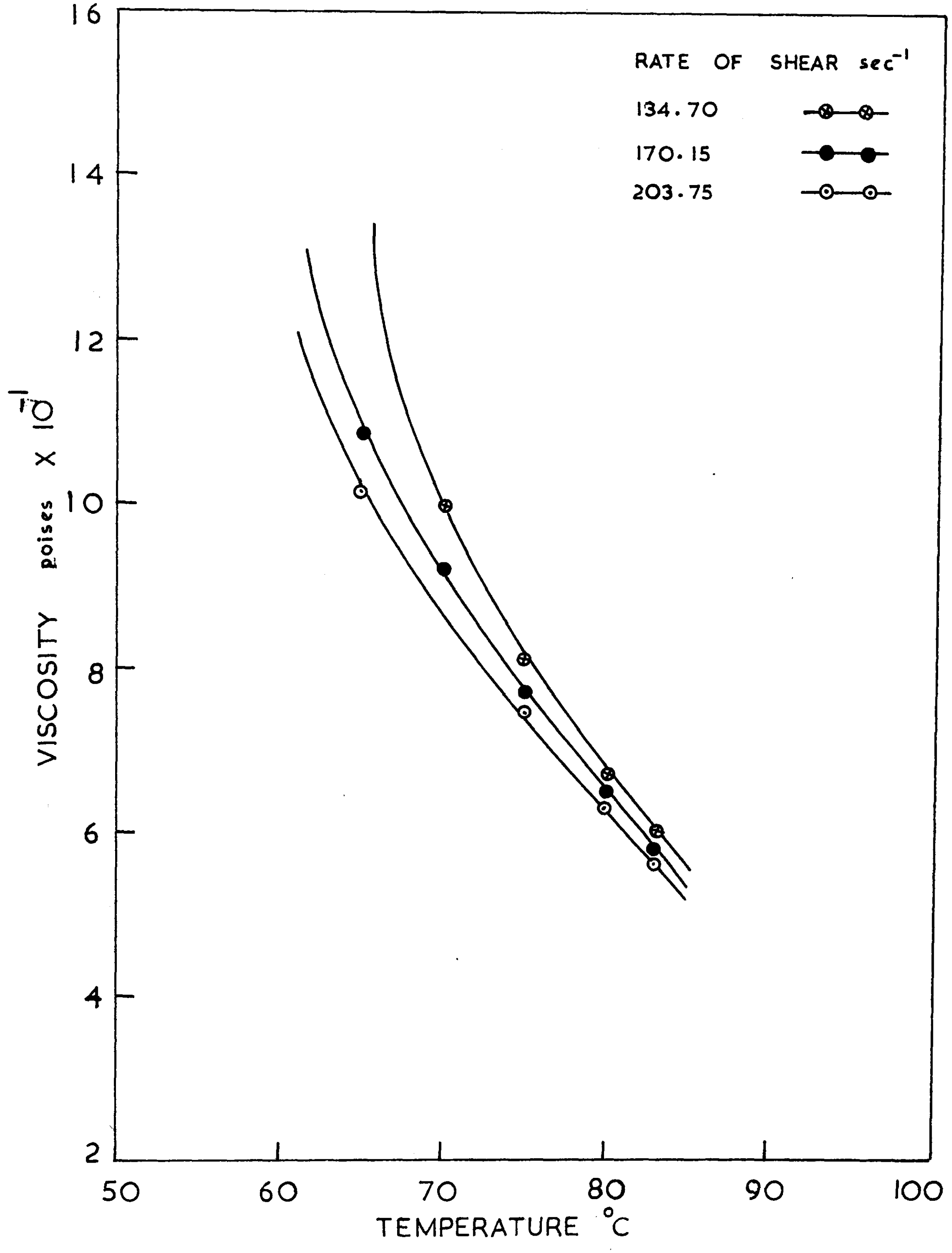

FIG. 24. EFFECT OF TEMPERATURE ON THE VISCOSITY OF SIZE MIX IV AT VARIOUS RATES OF SHEAR.

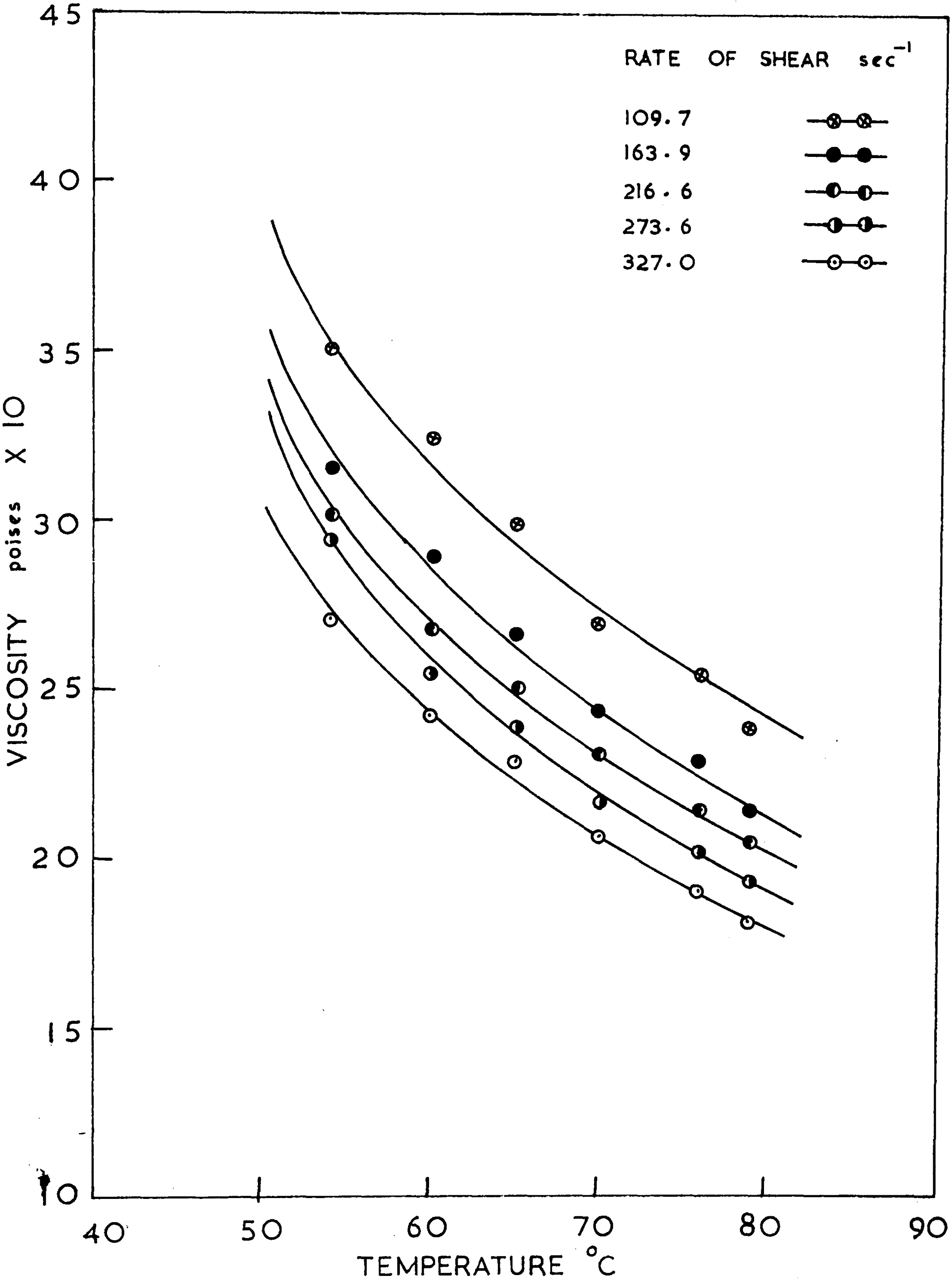

FIG. 25. EFFECT OF TEMPERATURE ON THE VISCOSITY OF SIZE MIX V AT VARIOUS RATES OF SHEAR.

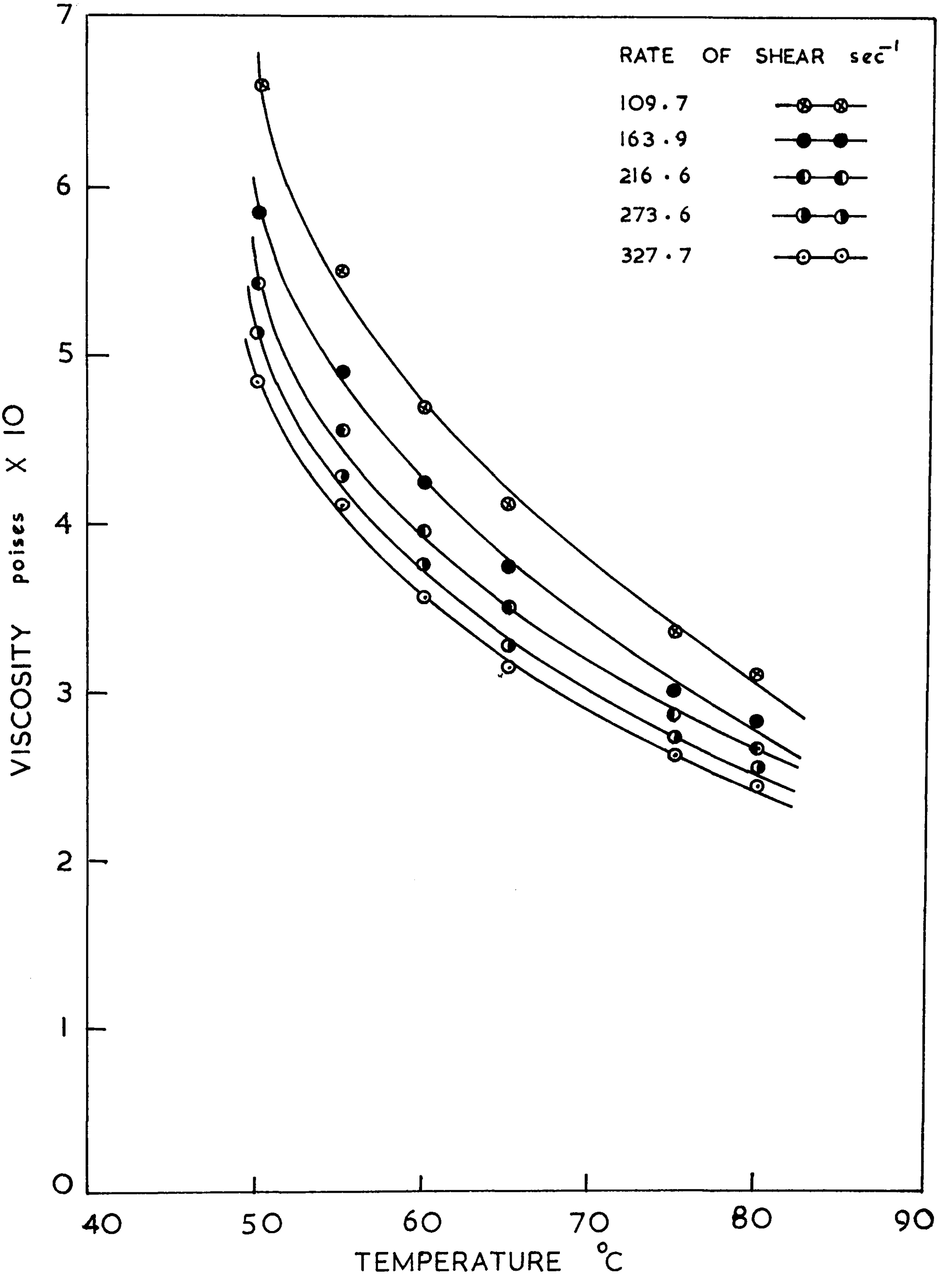

FIG. 26. EFFECT OF TEMPERATURE ON THE VISCOSITY OF SIZE MIX VI AT VARIOUS RATES OF SHEAR.

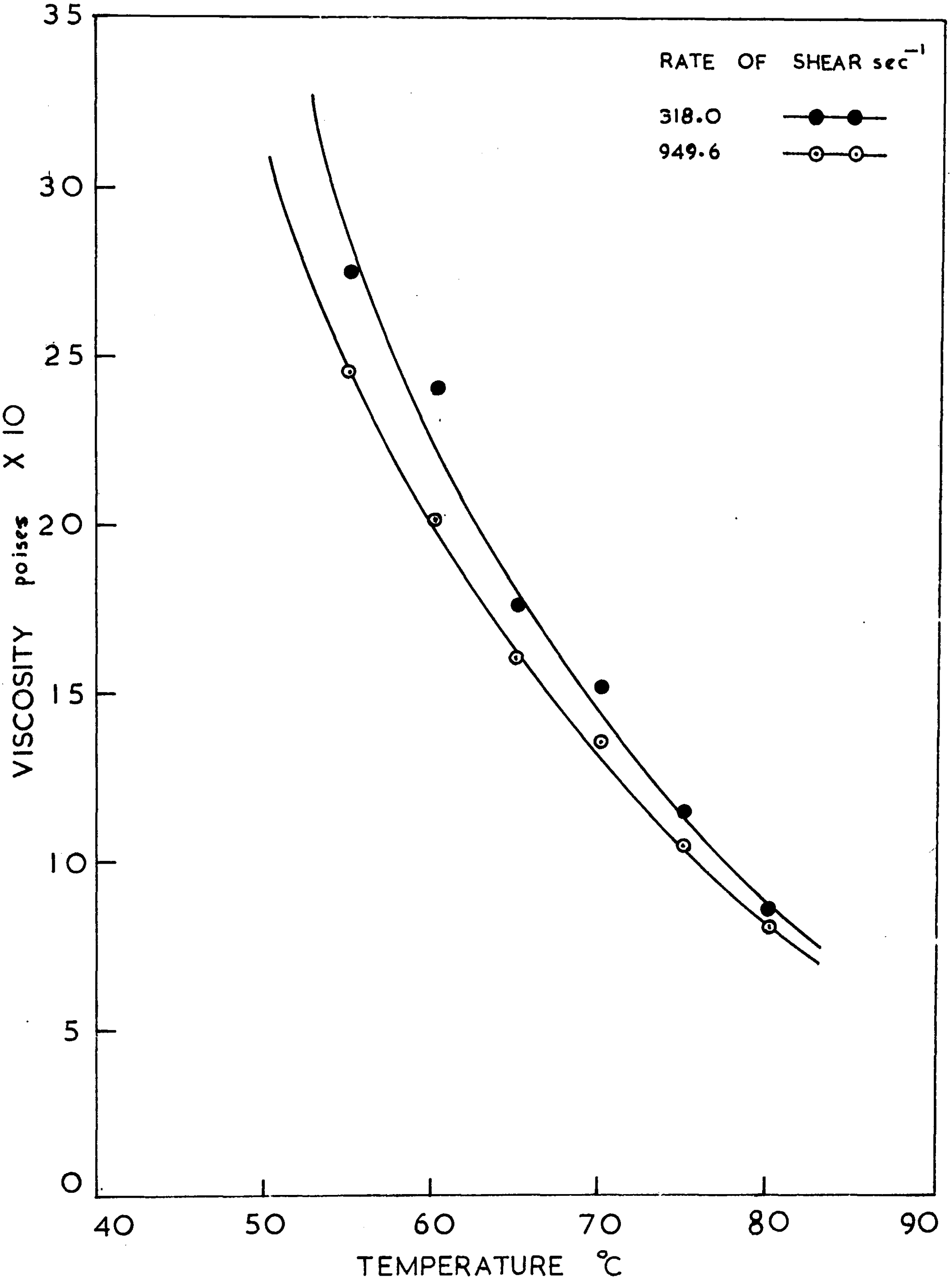

FIG. 27. EFFECT OF TEMPERATURE ON THE VISCOSITY OF SIZE MIX VII AT VARIOUS RATES OF SHEAR.

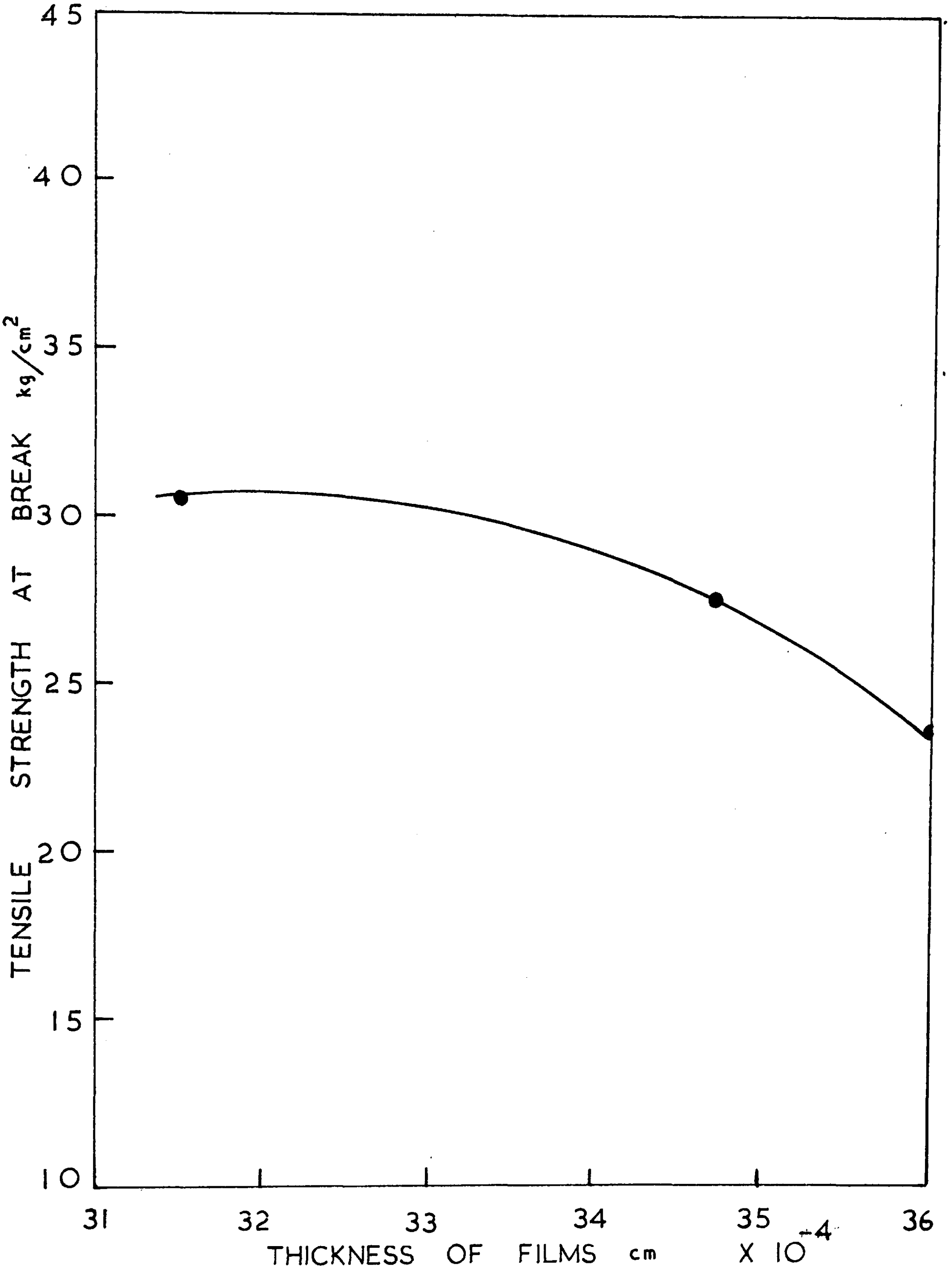

FIG. 28. EFFECT OF THICKNESS ON THE BREAKING STRENGTH OF FILMS OF SIZE MIX V.

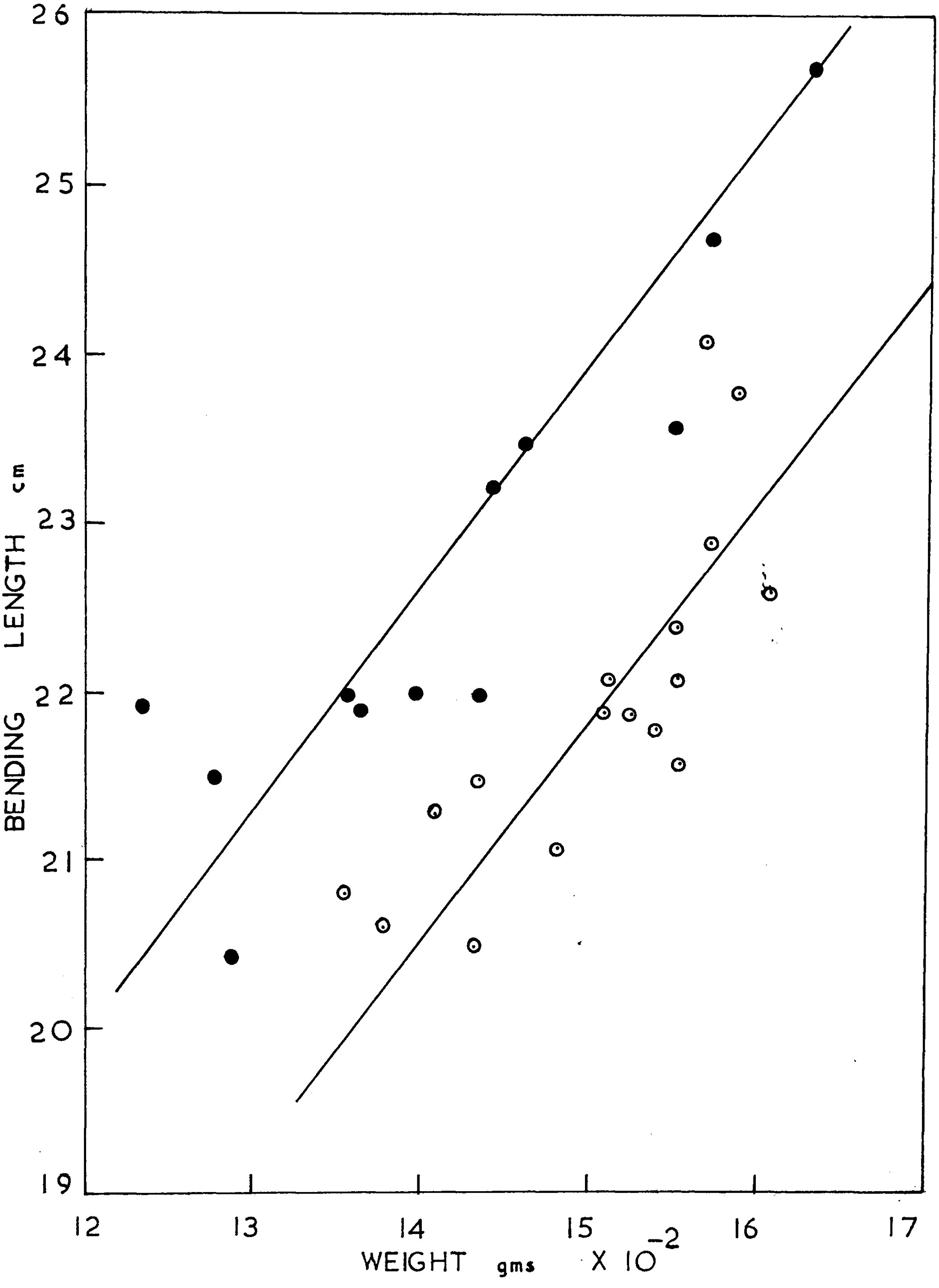

FIG. 29. EFFECT OF THICKNESS ON THE BENDING LENGTH OF FILMS OF SIZE MIX V.

(a) Black circles - 40% concentration.

(b) White circles - 50% concentration.

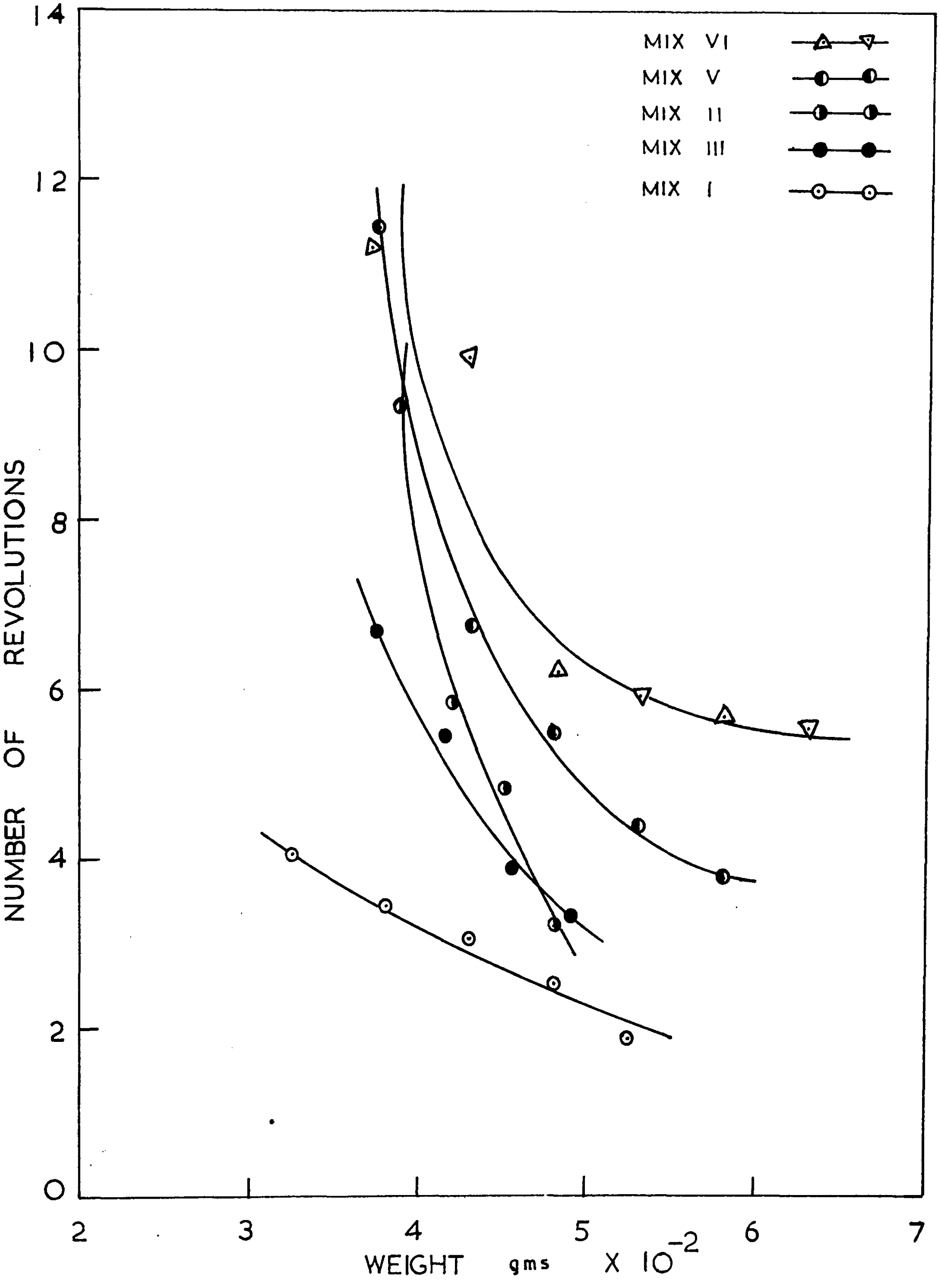

FIG. 30. EFFECT OF THICKNESS ON THE FLEXING STRENGTH OF FILMS OF VARIOUS SIZE MIXES.

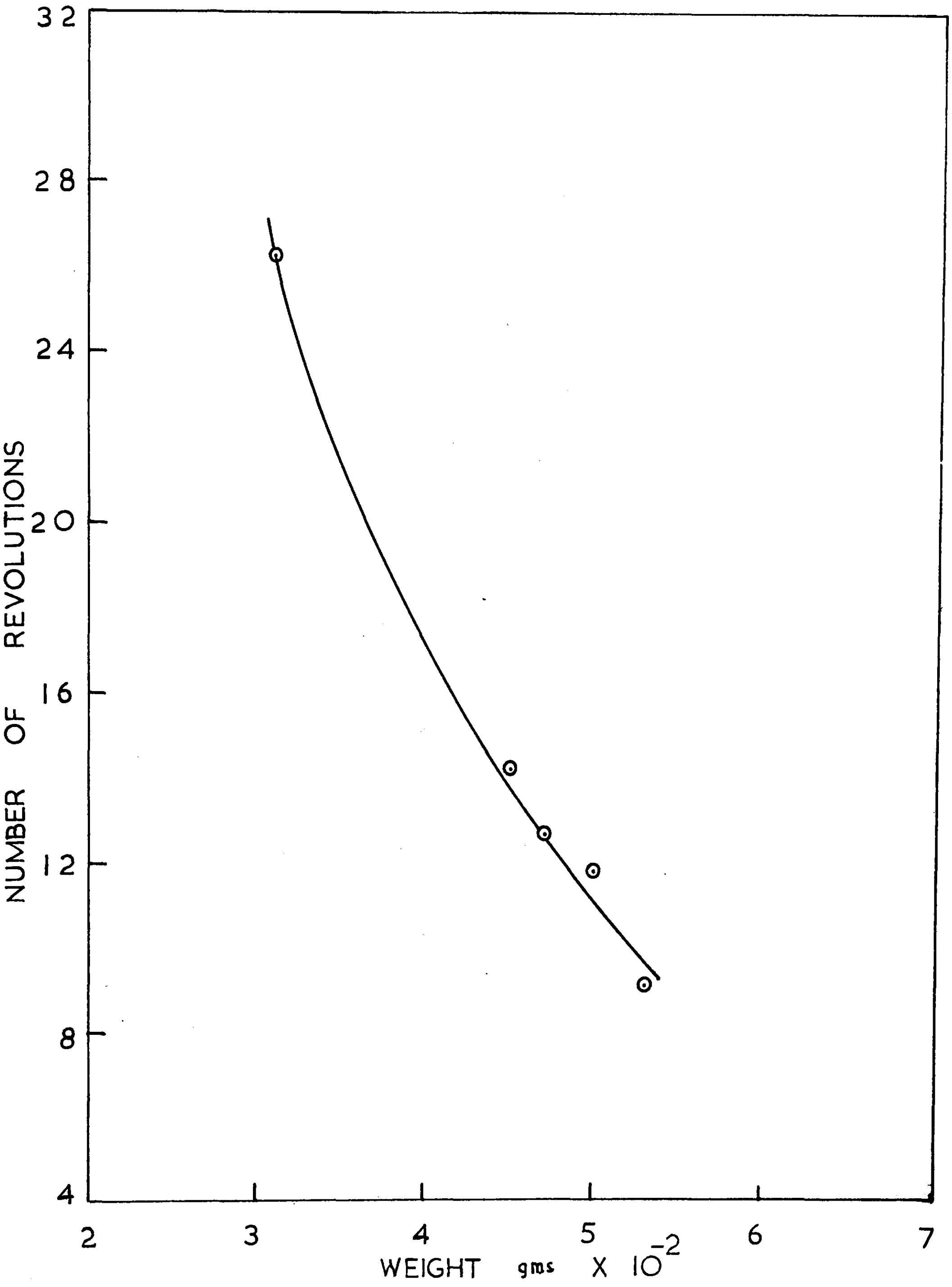

FIG. 31. EFFECT OF THICKNESS ON THE FLEXING STRENGTH OF FILMS OF SIZE MIX IV.

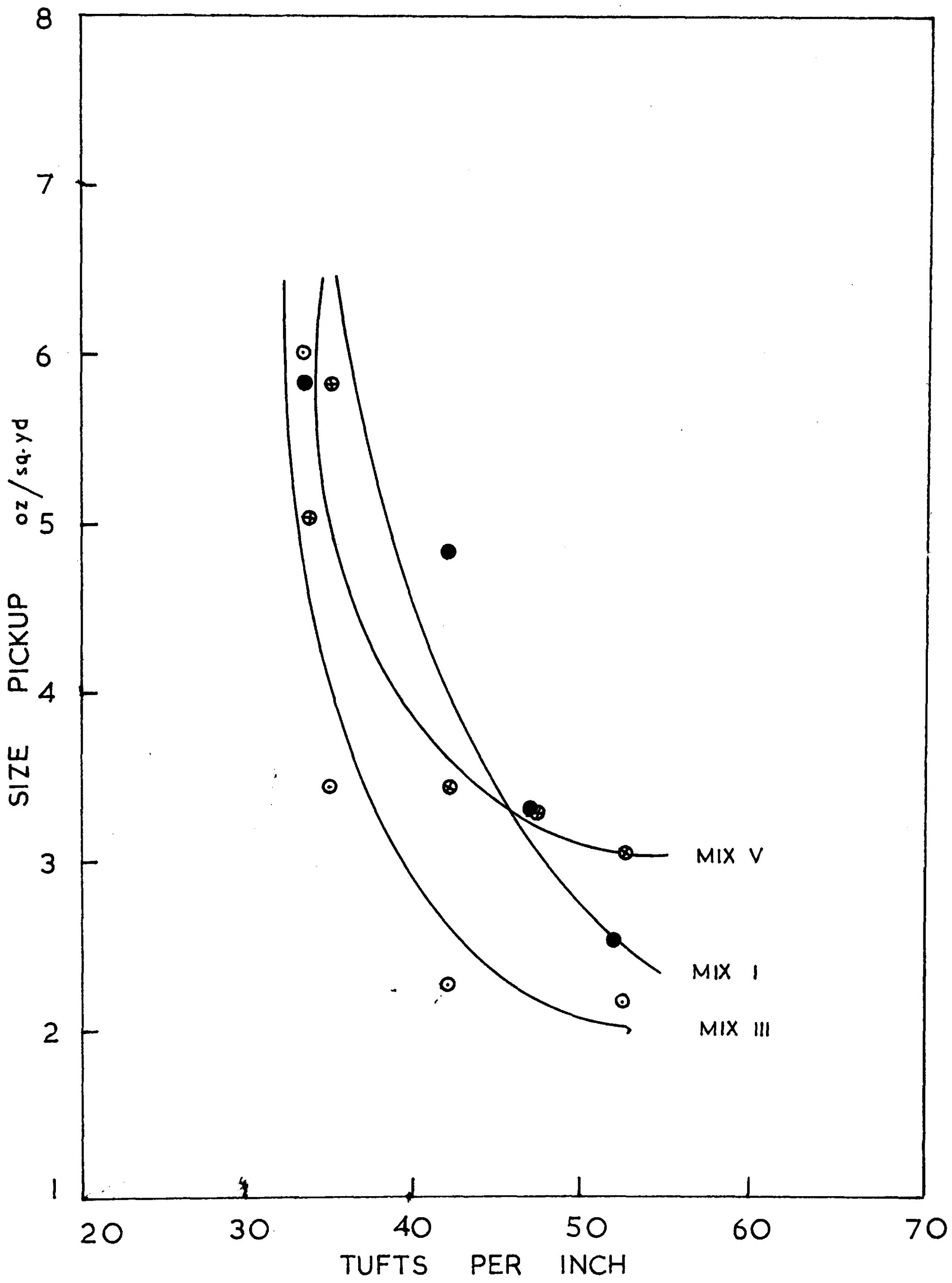

FIG. 32. RELATION BETWEEN TUFT DENSITY AND AMOUNT OF SIZE PICK-UP.

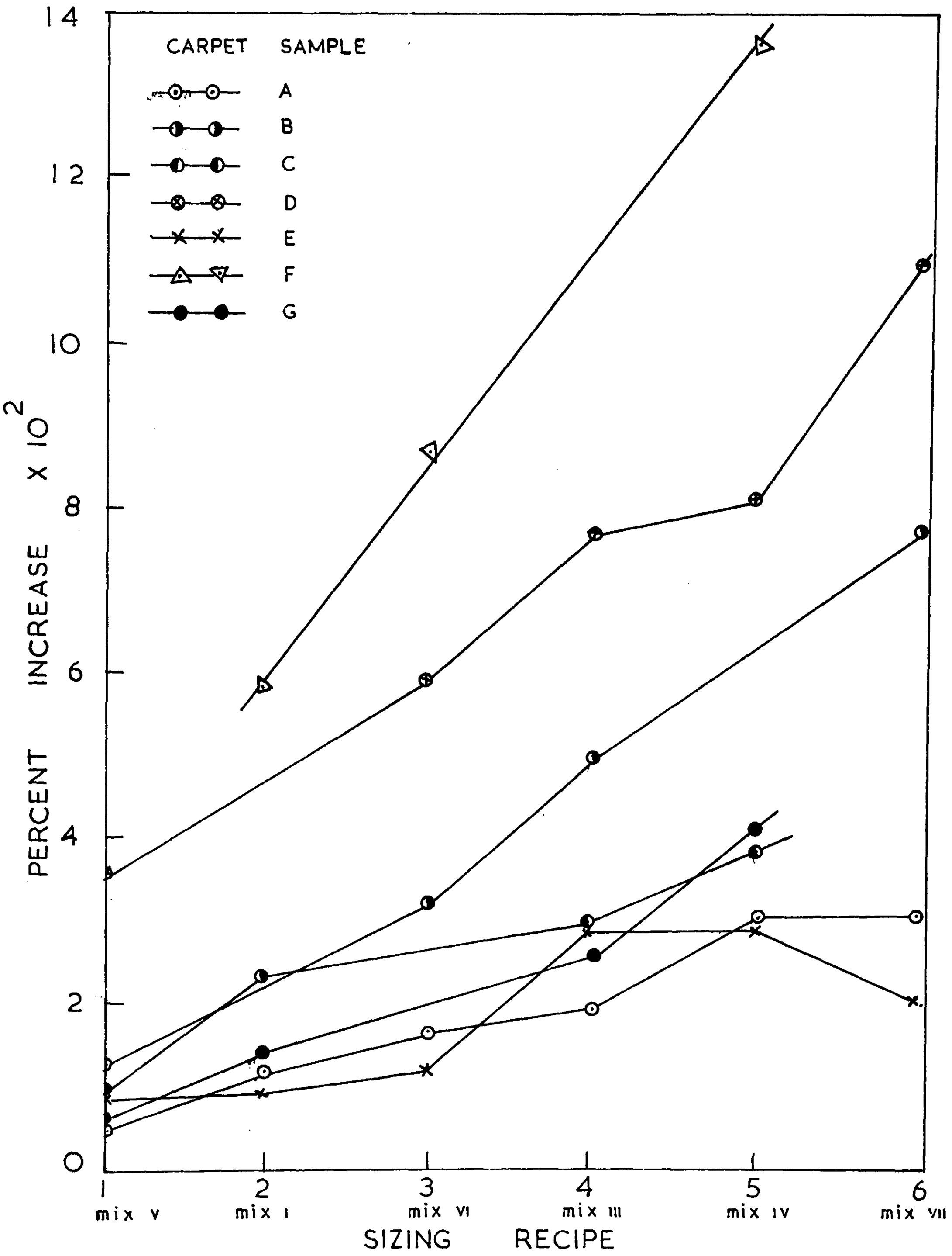

FIG. 33. EFFECT OF DIFFERENT SIZING MIXES ON PERCENT. INCREASE IN TUFT WITHDRAWAL FORCE.

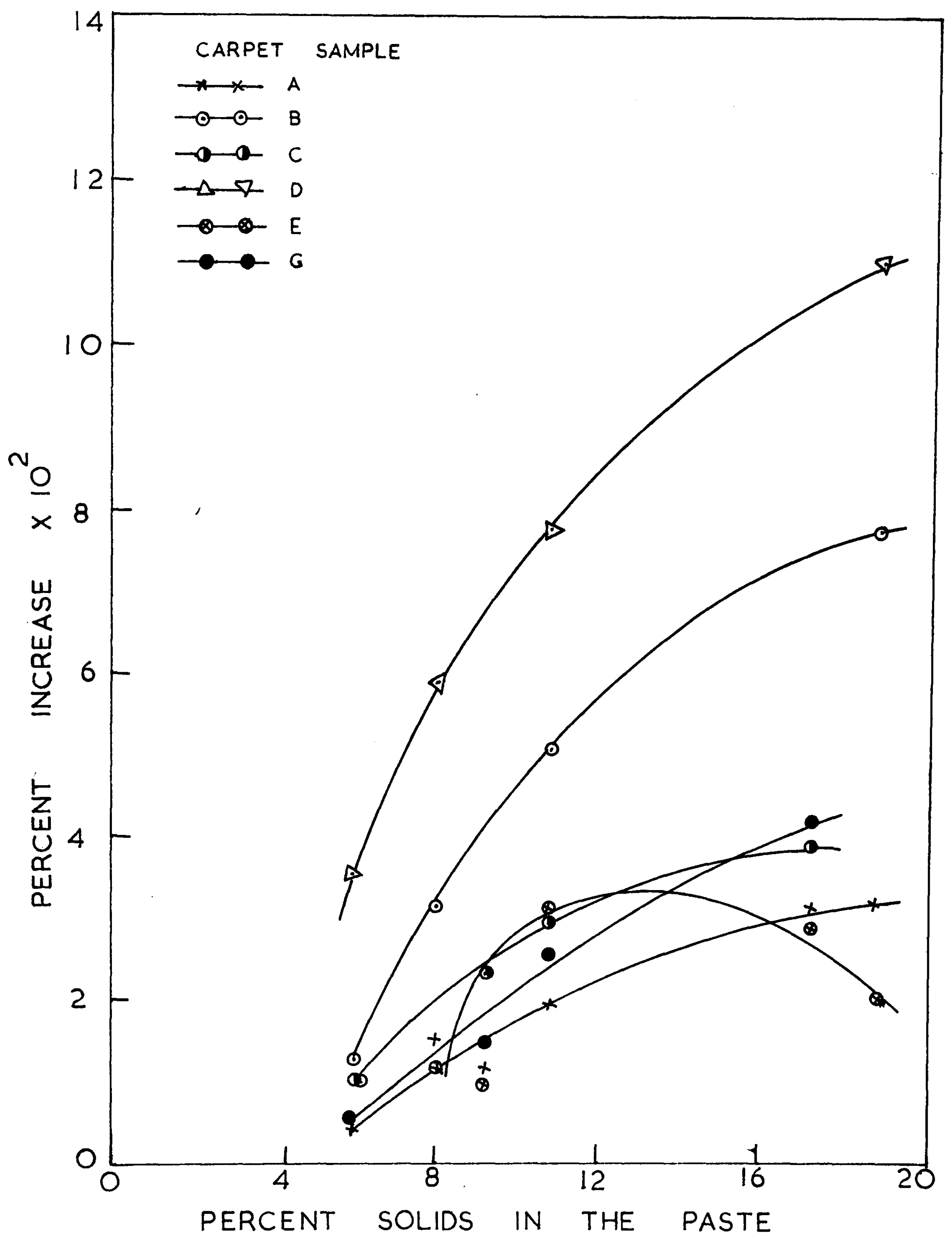

FIG. 34. RELATION BETWEEN PERCENT DRY SOLIDS IN THE PASTE AND PERCENT INCREASE IN TUFT WITHDRAWAL FORCE.