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Mechanical assessment of polyurethane impregnated fibreglass bandages for splinting

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Abstract

The introduction of polyurethane (PU) resin impregnated fibreglass bandages is likely to have a significant effect on modern orthopaedic practice. The manufacturers of these products claim many improved properties compared to plaster of Paris bandages, such as, high strength to weight ratio, rapid setting time and high radiolucency. This paper reports on a series of mechanical tests designed to assess the strength, flexibility, working time and wear properties of the current range of fibreglass bandages and to compare them with plaster of Paris bandages. The results have clearly demonstrated that the fibreglass bandages are mechanically superior and offer numerous advantages over plaster of Paris for use as the definitive casting material for both weight-bearing and non-weight-bearing casts.

Introduction

The introduction of composite materials technology to prosthetics and orthotics practice offers major advantages in terms of strength to weight ratio and design flexibility. The last few years has seen a rapid growth of resin impregnated fabric bandages, the most common being knitted fibreglass fabric impregnated with a polyurethane resin. The use of a continuous filament fibreglass to produce a fabric which has the strength and flexibility for casting can be achieved by the selection of the appropriate glass fibre diameter and the pattern of the fabric knit. During manufacture the knitted fibreglass roll is impregnated with a urethane pre-polymer resin. The formulation of this pre-polymer resin contributes to the characteristics of the cured polyurethane and hence the properties of the final cast. The bandages are activated by water immersion and wrapped in a similar way to plaster of Paris (POP) bandage.

There is little in the published literature on the properties of fibreglass bandages (Gill & Bowker, 1982; Rowley et al, 1985; Wytch et al, 1987). A series of mechanical tests was devised to supplement the existing knowledge of these materials and to provide a means of comparison of the currently available fibreglass bandages. There are no laid down standards for the properties of these composites but British Standard BS2782: 1978 on the testing of plastics provided guidance for some of the test procedures. Plaster of Paris bandage has been included as a reference for comparison with these materials.

The advantages of casts constructed from PU impregnated fibreglass bandages compared to plaster of Paris (Gypsona) bandages include greater strength, lighter weight, better X-ray transmission, cleaner application and a much faster curing time (weight bearing can be achieved within thirty minutes). The major disadvantages with the PU impregnated fibreglass bandages is their high cost and problems with long-term storage. The resin accumulates in the lowest part of the bandage during storage and

Table 1. Materials studied

Type of bandage	Product name	Activation procedure
100% Knitted fibreglass impregnated with polyurethane resin	Dynacast XR Scotchcast 2 Duraset-lite Zimmer Delta-lite	Immerse in water at 22°C for 5 secs, squeezing 3 times
Plaster of Paris on Leno weave Cotton Bandage	Gypsona	Immerse in water at 25°C for 10 secs squeezing firmly on removal

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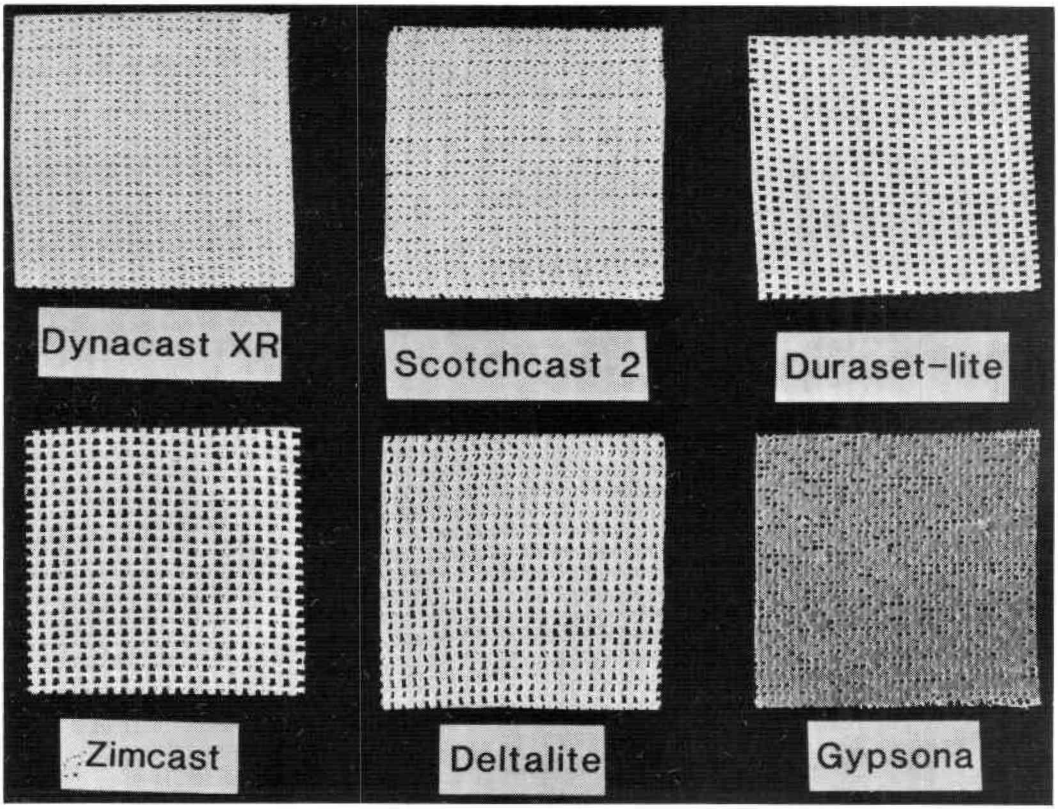

Fig. 1. Samples of PU resin impregnated fibreglass and plaster of Paris bandage. Variation in the knit of the different fibreglass bandages can be seen. Compare the fine knit of Dynacast XR and the coarse knit of Zimcast.

premature polymerisation can occur, the shelf life is therefore limited to about 24 months. The fibreglass bandages do not however have the unrivalled moulding properties of POP bandages (Fig. 1).

Materials and method

A range of mechanical tests was performed on five of the currently available polyurethane impregnated fibreglass bandages and plaster of Paris bandage. In order to minimize experimental errors all sample preparation and testing was carried out by one of the authors. The bandages were conditioned for at least 48 hours at a temperature of 21($\pm$1) degrees Celsius and a relative humidity of 65% ($\pm$2%) before use. All bandages were activated according to manufacturers instructions (Table 1).

The eight mechanical tests described below provide a comparison of the currently available fibreglass bandages. However, four of these tests also provide a comparison of the fibreglass with plaster of Paris bandages. An Instron 1195 materials testing frame was used for all except the wear tests. Three types of test sample were used depending on the test method employed, either 50mm or 100mm diameter cylinders, or rectangular specimens of varying dimensions constructed from 100mm (4″) wide bandage. Cylinder diameter, number of layers, deflection and rate of loading were chosen to represent the intended use of the materials under severe conditions. Problems of controlling bandage tension during the preparation of the cylindrical test samples encountered by Gill & Bowker (1982) were overcome using a purpose built test jig. This is explained in the cylinder compression test method below. Mechanical properties of the bandages were obtained using rectangular samples prepared and tested in accordance with British Standard BS 2782 :1976(1986). All tests were carried out on a minimum of six samples of each material and average results are shown below.

1. Cylinder compression test

The aim of the cylinder compression test was primarily to provide a value for the final cast strength of both the fibreglass and plaster of Paris bandages and also provide data on the rate of strength build up of the fibreglass materials. Immediately after bandage activation the 100mm (4") wide bandage roll was transferred to a toolmaker's jig comprising a base plate supporting two tailstock centres. The bandage core was supported between the tailstock centres and wrapped onto a 100mm diameter motor driven mandrel revolving at a constant speed of 15rpm. This speed maintained a moderate tension in the bandage whilst providing a consistent method of wrapping cylinders from the bandage rolls. Cylinders four layers thick were removed from the mandrel after 30 minutes and transferred to the test jig attached to the Instron shown in Figure 2a.

The cylinders were then compressed diametrically by 10mm, perpendicular to the longitudinal axis of the cylinder, at a rate of 5mm/min and the load recorded. Compression tests were carried out after 30 minutes, 60 minutes, 24 hours and 72 hours. The Gypsona cylinders were not tested after 30 or 60 minutes as they were insufficiently rigid to maintain their shape on removal from the mandrel.

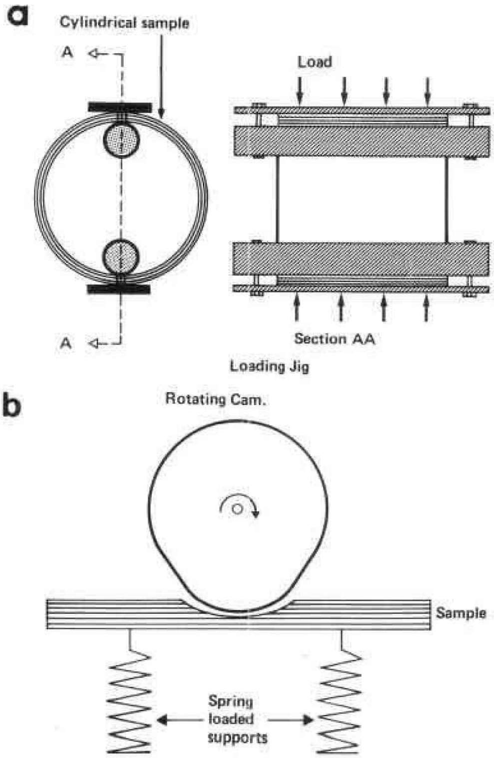

Fig. 2. Schematic of apparatus for: (a) cylinder compression test (b) wear test.

2. Water immersion test

The aim of this test was to determine the effects of water immersion on the strength of the fibreglass bandages. The deterioration of plaster of Paris bandage when exposed to water is well known. Cylinders of each bandage four layers thick were wrapped in a similar fashion to those used in the cylinder compression test and following preparation were allowed to cure for 24 hours in a controlled laboratory environment. They were then subjected to a cylinder compression test. Each sample was then fully immersed in water at 20 degrees Celsius for 60 minutes and re-tested. Subsequent tests were carried out within a 24 hour period after water immersion.

3. Cyclic flexure test

The purpose of this test was to determine the initial rate of strength build up of the fibreglass bandages. Cylindrical samples, 50mm diameter and four layers thick, were prepared in a similar manner to those for the cylinder compression test using the same apparatus but with a smaller diameter mandrel. Each sample was wrapped onto the mandrel and immediately transferred to the Instron test jig. The sample was then subjected to a cyclical loading to produce a deflection of ±2.5mm about the unstressed position using the Instron cycling facility. The load required to produce this deflection was recorded over a 60 minute period.

4. Unrolling tension test

The aim of this test was to provide an indication of the working time for the fibreglass bandages. That is, the time an applicator would have to wrap a bandage before the resin had cured sufficiently to make it difficult to unwrap from the roll. The unrolling tension of the bandage is defined as the time taken for the bandage unrolling force to reach a load of 5N. This value was chosen as manual bandage unwrapping becomes difficult at this load. Bandages were activated in the recommended way and a spindle inserted through the core of the bandage roll. The spindle was attached via a support jig to the load cell of the Instron to record the force required to unwrap the bandage. The free end of the bandage was clamped to the moving crosshead and a constant bandage unrolling rate of 50mm/min. was applied.

5. Rate of lamination strength build up

The purpose of this test was to provide an indication of the time required for the bandage to achieve adequate bond between adjacent layers in a cast. The rate of lamination strength build up was defined as the time at which a delamination load of 50N was reached. This value was chosen since a cured bandage could not be manually unwrapped at this load. The unrolling procedure was similar to the previous test except that the bandage was initially wrapped onto a 50mm diameter mandrel. The bandages were activated and then wrapped onto the mandrel following the same procedure as used in the cyclical flexure test but leaving a 10 cm free end. The mandrel was placed in the Instron and held between tailstock centres so that it was able to rotate whilst the free end of the bandage was firmly clamped and unrolled at a rate of 50mm/min.

6. Three point bend test

The purpose of this test was to determine the flexural modulus and flexural strength of both fibreglass and plaster of Paris bandages. After activation, bandages 100mm (4″) wide were prepared into slabs on a smooth flat surface and covered with a flat board. A uniformly distributed load was placed on top of the board to ensure all slabs were of an even thickness. The slabs were allowed to cure for 72 hours at 22 (±1) degrees Celsius and were then cut using a bandsaw into samples, 25mm by 100mm and four, five and six layers thick. Samples were tested in accordance with BS 2782 (1978) using a three point loading jig attached to the Instron. The loading rate was 10mm/min. Each material was tested longitudinally and transversely.

7. Tension test

The aim of this test was to determine the fracture stress of the bandage when subjected to a tensile load. Sample preparation was similar to that for the three point bend test except that specimens had dimensions 20mm× 150mm and were 2, 3 and 4 layers thick. The test procedure was carried out in accordance with BS 2782 :1976(1986) with a loading rate of 10mm/min.

8. Wear test

The purpose of this test was to determine the wear resistance of fibreglass and plaster of Paris bandages. Bandages were prepared in slab form in a similar way to the three-point bend test to give a sample thickness of 8mm (±1mm). Slabs were cured for 72 hours before being cut into samples 20mm×170mm×8mm using a bandsaw. Each sample was weighed and measured accurately before and after testing. The test apparatus is shown in Figure 2b. A motor driven cam 25mm wide rotating at 880rpm had abrasive paper attached to the outer surface of the cam prior to each test. Samples of material were clamped to the test jig for five minutes and the sample mass and volume loss determined.

Results and discussion

Variations in bandage mass and width have been included in the results to provide a reliable comparison between specimens. The material strength is therefore defined as the strength per unit mass per unit width of the bandage and has units of N/kg.mm.

1. Cylinder compression test

The results in Table 2 show that the fibreglass materials reached over a third of their final (72 hour) strength within 30 minutes and reached over 90% of their final strength within 24 hours. The results show that the 30 minute strength of the fibreglass bandages exceeded the final strength of Gypsona and after 72 hours they were more than three times stronger. Zimcast was found to be the strongest of the fibreglass materials and also had the greatest 30 minute strength.

2. Water immersion test

The effect of the water immersion on the strength of the fibreglass bandages can be seen in Figure 3. All of the materials showed a decrease in strength after immersion. The

Table 2: Cylinder compression test results

Material	Strength/Mass ratio (N/kgmm)			
	30mins	60mins	24hrs	72hrs
Dynacast XR	7.34	15.84	24.35	25.43
Scotchcast 2	9.08	11.62	22.70	22.70
Duraset-lite	6.04	9.38	20.90	20.95
Zimmer	18.84	21.20	34.25	34.81
Delta-lite	7.27	12.75	29.20	28.95
Gypsona	—	—	4.75	6.09

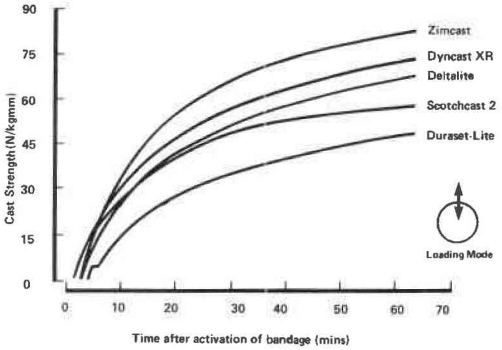

Fig. 3. Water immersion test: effect on strength.

strength of the materials, however, continued to decrease over the next four hours before recovering to 90% of their original strength after 24 hours. The material least affected by water immersion was Delta-lite which at the worst condition lost only 10% of its original strength compared to Scotchcast 2, the most affected, which, at the worst condition had lost 53% of its original strength.

3. Cyclic flexure test

All of the fibreglass bandages showed a rapid increase in strength over the first 20 minutes (Fig. 4). The rate of increase slowed thereafter. Zimcast showed the fastest rate of strength development and Duraset-Lite the slowest. However in practice all materials build up their strength sufficiently quickly to allow weight bearing within 30 minutes.

4. Unrolling tension test

The working time of the fibreglass materials ranged between 3.83 mins. and 2.92 mins. (Table 3). This is more than adequate for applying a bandage of this type.

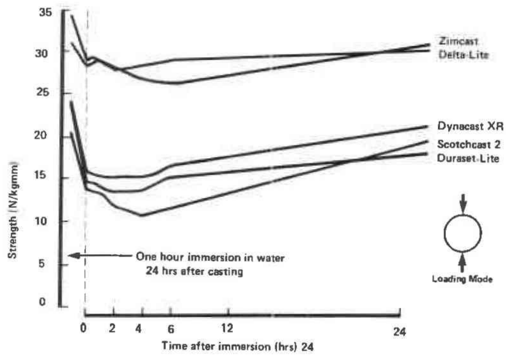

Fig. 4. Cyclic flexure test: rate of strength build up.

Table 3. Critical material times

Material	Working time (mins)	Time to reach bandage lamination strength of 50N (mins)
Dynacast XR	3.28	8.02
Scotchcast 2	3.05	4.77
Duraset-Lite	2.97	8.32
Zimmer	3.83	10.35
Delta-Lite	2.92	5.00

5. Rate of lamination strength build up

Force/time graphs for each material showed large variations in lamination strength between different areas of the bandages. This was due to resin accumulation in the lowest part of the bandage during storage and is one of the disadvantages of this type of material. However if the bandages are regularly turned during storage this problem can be largely overcome. The results in Table 3 show that all the fibreglass bandages reached a satisfactory lamination strength within 11 minutes. This test also showed that all fibreglass bandages reached a lamination strength of over 100N and as much as 200N in the case of Scotchcast 2.

6. Three point bend test

The elastic modulus in flexure (Fig. 5, top) and the flexural stress at maximum load (Fig. 5, bottom) was obtained from a three-point bend test for each material. It was found that these material properties varied significantly when tested in different directions. Samples were therefore tested longitudinally and transversely to the bandage roll. The flexural modulus (stiffness) of the fibreglass materials was greater in the transverse direction than in the longitudinal direction. The opposite was true for Gypsona.

The fibreglass materials were able to withstand higher flexural stresses in the transverse direction than in the longitudinal direction. The opposite was true for Gypsona. The maximum flexural stresses in the fibreglass materials were up to three times greater in the longitudinal direction and up to ten times greater in the transverse direction than Gypsona.

When a below-knee cast is stressed the major bending forces act across the width of the bandage particularly where the calf and foot cylinder meet. It is therefore mechanically desirable to have greater strength and stiffness transversely than longitudinally in the bandage.

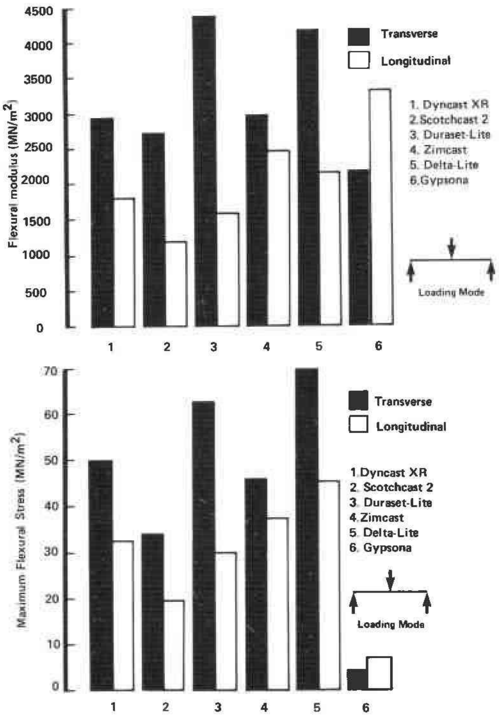

Fig. 5. Top, elastic modulus in flexure: 3-point bend test. Bottom, flexural stress at maximum load: 3-point bend test.

This was found to be the case for the fibreglass bandages.

7. *Tension test*

The difference in properties between the transverse and longitudinal directions can be seen in Figure 6. The fibreglass materials fractured at stresses of up to five times greater than Gypsona in the longitudinal directions and

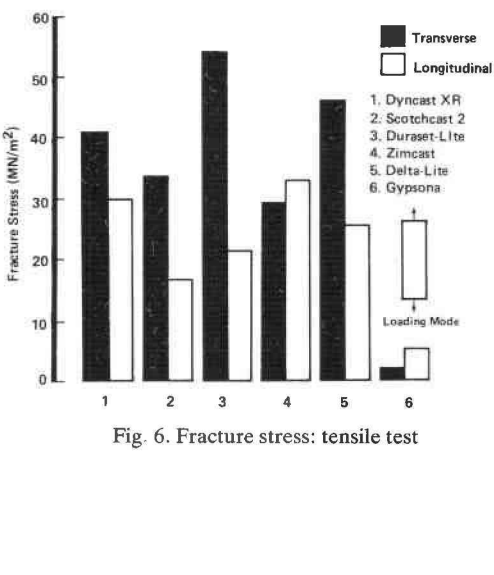

Fig. 6. Fracture stress: tensile test

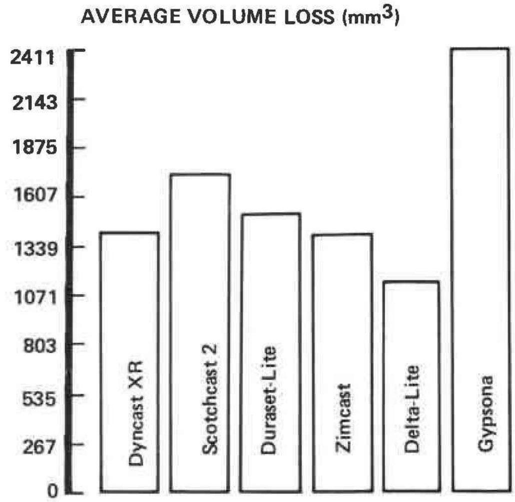

Fig. 7. Volume of material lost during wear test.

up to 20 times greater in the transverse direction. The greatest fracture stress was shown by Duraset-lite in the transverse direction and Zimcast in the longitudinal direction.

8. *Wear test*

The results in Figure 7 show that all of the fibreglass materials were more wear resistant then Gypsona, losing significantly less volume of material during testing. Delta-lite was the most wear resistant fibreglass material being more than twice as hard wearing as Gypsona.

Conclusions

The mechanical tests have shown that the fibreglass materials are mechanically superior to plaster of Paris. They are affected by prolonged contact with water but the effects are not severe and they recover 90% of their strength within 24 hours. The rate of strength build up of the fibreglass materials is rapid enough to allow weight-bearing often only 30 minutes. Gypsona is not recommended for weight-bearing until 72 hours. The bandages have an average working time of over three minutes and reach an acceptable lamination strength after seven minutes.

The fibreglass materials are stronger and stiffer in the transverse rather than the longitudinal direction whereas the reverse is true for Gypsona. This feature being a very important advantage of fibreglass bandages compared to Gypsona when considering the direction of loading in a cast. The fracture stress, typically 22 $MN.m^{-2}$ longitudinally and 32 $MN.m^{-2}$ transversely, of the fibreglass bandages compared to $4MN.m^{-2}$ and $2MN.m^{-2}$ respectively for Gypsona demonstrated the mechanical superiority of these materials. The fibreglass bandages were also more hard wearing than Gypsona.

In summary, resin impregnated fibreglass bandages make lighter, stronger and more durable casts than Gypsona and are capable of load bearing within 30 minutes. However, other considerations such as conformability, mouldability, ease of removal and price need to be taken into account when assessing the suitability of these bandages for orthopaedic splinting.

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