A CLINICAL AND EXPERIMENTAL STUDY OF PLASTER OF PARIS BANDAGES IN CANADA

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THE SUITABILITY of a plaster of Paris bandage for external skeletal fixation depends not only on the properties of the bandage itself but also on the techniques used by the orthopædic surgeon. Often, the surgeon's technique is influenced by the characteristics of the bandage available to him.

The properties of plaster of Paris bandages have changed greatly since their first use by Matthysen, in 1852.[1] His bandages were made by simply rubbing finely powdered plaster of Paris into strips of coarse-meshed cotton, which were then loosely rolled into bandages. Today, the modern, more complex plaster of Paris bandages are made with improved supporting cloth, and better plaster of Paris. They contain additives to modify the setting time, wetting characteristics, and the texture and appearance of the plaster. This results in greater ease of application of the bandage.

Since the most important bandage constituent is the plaster of Paris, an understanding of its chemistry is important in relation to good plaster technique. Plaster of Paris is produced by removing the impurities from the mined gypsum and then heating it under controlled conditions to reduce the amount of water of crystallization according to the following equation:

$$\underset{\text{GYPSUM}}{2\,CaSO_4 . 2\,H_2O} + \text{Heat} \rightleftharpoons \underset{\text{PLASTER OF PARIS}}{2\,CaSO_4 . \tfrac{1}{2}\,H_2O + 3\,H_2O}$$

It is ready for use in orthopædic bandages after the addition of certain additives, such as catalysts to change the setting time.

When immersed, plaster of Paris bandages take up water, reversing the above equation to reform crystalline gypsum. If this process is followed microscopically, it is possible to see crystals form, grow and interlock to produce a solid structure. Much of the ultimate strength of the plaster of Paris cast is due to this interlocking of crystals. Those factors which affect proper crystal formation, therefore, affect the strength of the cast. This is illustrated by the work of Luck.[2] His photomicrographs show that plaster of Paris which was not disturbed during the setting process has compact interlocking of crystals. On the other hand, sparse interlocking of crystals occurs in plaster of Paris which has been disturbed after the critical point in the setting process.

The present study, using three experimental bandages, was carried out to examine the techniques used by orthopædic surgeons in Canada and to find out the properties desired by these surgeons in a plaster of Paris bandage. In order to obtain this information, it was deemed necessary to make this study as comprehensive as possible. This was accomplished by carrying it out at 12 hospitals across Canada located at Montreal, Toronto, Kingston, Winnipeg, Saskatoon, Edmonton and Vancouver. More than 35 Canadian orthopædic surgeons contributed to the data presented in this paper.

EXPERIMENTAL

A number of experimental plaster of Paris bandages were prepared possessing different compositions. Three of these bandages were selected which differed in such properties as setting time, plaster loss, and the "feel" of the wet bandage during application. The first was an extra-fast setting bandage (two to five minutes) with a very smooth, creamy plaster mass but a low binder content. This bandage lost up to 35% of its plaster of Paris content when squeezed. The second bandage was also an extra-fast setting one, but it contained more plaster and a higher content of binder than the first. Although not as creamy in texture as the first, it retained more of its plaster after wetting and therefore was potentially stronger. It was possible to squeeze excess water from this bandage without losing more than 5% of its plaster of Paris content. The third bandage was similar to the second in formula, except for a lower content of catalyst which made it a slower setting bandage (five to eight minutes).

LABORATORY TESTS

Setting Time

Three methods were used in the laboratory to determine the setting time of the experimental bandages. These methods were a "hand feel" method, a penetration method using a modified Vicat needle, and a thermal method. Values obtained by the different methods were in good agreement.

Compressive Strength

To measure and compare the compressive strengths of the different experimental bandages, cylinders were made by wrapping the bandages concentrically on a two-inch-diameter brass core. These cylinders were then removed from the core and crushed at fixed times. The force required was measured in pounds by the Dillon mechanical pressure gauge of the compression tester shown in Fig. 1.

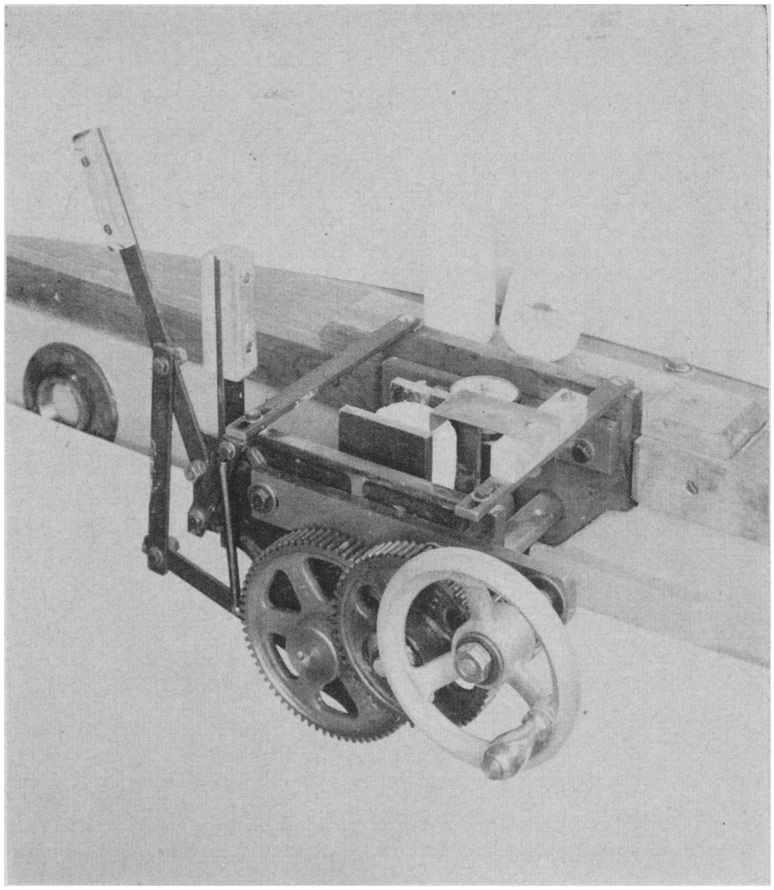

Fig. 1.—Compression tester.

Plaster Loss

The plaster lost by a bandage after soaking and removing the excess water by squeezing was determined by weighing the expressed plaster, using standard quantitative analytical procedures.

CLINICAL TEST

In order to evaluate the performance of these bandages as accurately and thoroughly as possible, two separate records were kept. One form was completed by the surgeon applying the cast and another form by the observer conducting the test. The surgeon's form recorded data obtained during application, during wearing, and upon removal of the cast. The most important data recorded during application, in addition to personal data on the patient such as age and sex, were type of cast, temperature of water used for immersion of bandages, amount of plaster in the bandage, setting time, and mouldability of the bandage. The surgeon was asked to write down any pertinent observations made during the wearing of the cast. Finally, upon removal of the cast, the condition of both the cast and the patient's skin was recorded.

In the form filled out by the observer, the technique used by the orthopædic surgeon in the application of the bandage was emphasized. Because the same person observed several surgeons, a more valid comparison of surgeons' techniques and bandage performance in the different hospitals was obtained.

RESULTS AND DISCUSSION

The results of this clinical study are based on 614 casts of all types which represent the application of 4609 individual bandages. In Table I the number of each type of cast is given.

TABLE I.—TYPES AND NUMBERS OF CASTS APPLIED

Large casts	*No. applied*	*Smaller casts*	*No. applied*
Scoliosis plaster	9	Long leg casts	108
Body jacket	23	Leg cylinder (stovepipe)	34
Minerva jacket	2	Below knee cast	176
Bilateral hip spica	11	Arm cast	54
Unilateral hip spica	22	Forearm cast	136
Shoulder spica	15	Splints	17
Plaster beds	4	Finger casts	3

During the application of the bandages certain properties are desired in a plaster of Paris bandage by Canadian orthopædic surgeons. These properties, which greatly influence the speed and ease of application of the bandages, are given in Table II.

The desirable properties of a bandage after application are given in Table III.

TABLE II.—DESIRED PROPERTIES OF BANDAGE DURING APPLICATION

1. Rapid saturation	7. Smooth and creamy texture
2. No dry spots	8. No tendency to ridge
3. Low plaster loss	9. Mouldability
4. Should not telescope	10. Correct setting time
5. No loose threads	11. Non-irritating to doctor's hands
6. Rapid thickening of wet plaster mass	

TABLE III.—DESIRED PROPERTIES OF BANDAGE AFTER APPLICATION

1. High early cast strength	4. Freedom from irritation
2. Durability	5. Smooth finish
3. No delamination	6. White appearance

One of the most important and frequently discussed properties of the experimental bandages by orthopædic surgeons was the *setting time.* The opinion of an orthopædic surgeon regarding the setting time of plaster of Paris bandages depends not only on the type of cast to be applied, but on the surgeon's technique. Roughly, 75% of the doctors in this study preferred extra-fast setting bandages (two to five minutes). The other 25% desired the fast setting bandage (five to eight minutes). Several of the surgeons who preferred the extra-fast setting bandages for general use did express a liking for the slower setting bandage for certain specific types of casts.

The percentage of the casts made from the three different types of experimental bandages which were considered to have a satisfactory setting time is shown in Fig. 2. The shaded areas indicate the proportion of large casts as listed in Table I. Over 90% of the extra-fast setting bandages used were considered by the doctors to have a satisfactory setting time. This chart also indicates the percentage of casts which were considered to have set too quickly or too slowly. A large proportion of the unsatisfactory reports were for very fast setting bandages used on large casts, or slower setting bandages used on a small cast.

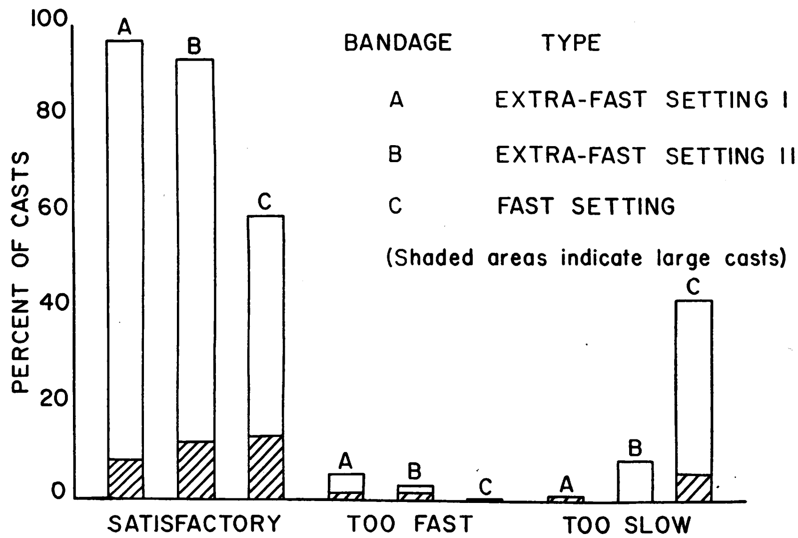

Fig. 2.—Opinion of Canadian orthopædic surgeons regarding the setting time of experimental bandages.

No other property of the bandages received more comment than the "feel" of the wet bandages during application. To most surgeons, a smooth, creamy feel was more than an æsthetic property. Although this property is somewhat subjective in nature, it was considered important for good moulding, proper fusion of cast layers, to prevent ridging and to aid in the overall ease of application. Most of the doctors desired a smooth, creamy bandage with adequate loose plaster. Bandages not satisfying these requirements were described as woody, gritty, stiff, rough or too thick.

Proper mouldability was tied in with each of the foregoing properties. Bandages were criticized for having poor moulding properties if they were not smooth and creamy enough and also if their setting time was too short to allow proper handling.

The most important property of a bandage is determined by the condition of the cast on removal from the patient. This condition depends upon the durability and the strength of the bandages used in the cast. The surgeon does not wish to have softening or breakdown of his cast, not only because of the inconvenience of repairing or replacing the cast but because of the danger of aggravating the injury to the patient. The resistance of the cast to breakage or softening is related to the strength of the bandage.

Fig. 3 illustrates the percentage of the casts made from the different types of experimental bandages in this study which were in good condition on removal. The number of casts in poor or fair condition on removal is also shown. A cast was considered in *good* condition if the

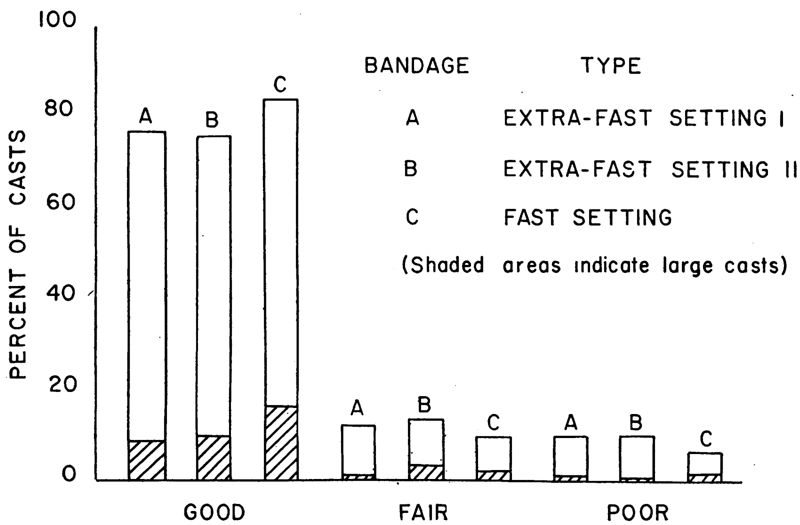

Fig. 3.—Condition of casts on removal.

surgeon classed it as satisfactory and it showed no more than the usual wear. A *fair cast* indicated one which was softened or excessively worn. A *poor cast* was one which was cracked, broken, or softened so that it was, or should have been, repaired or replaced. Casts broken by the patient falling or by any other accident were discarded and not counted in this study.

Roughly, 10% of all the casts applied in this study were in poor condition on removal. No comments were received to indicate that the incidence of cast breakdown was higher with the experimental bandages than that encountered in usual practice. This would suggest that such a rate of cast failure is generally accepted by Canadian orthopædic surgeons. It should be noted that the breakdown rate at different hospitals differed greatly. This is related not only to the type of patient treated, but also appears to bear some relation to the technique of bandage application employed by the surgeon. A few hospitals reported a breakdown rate much lower than the average.

Casts made from the slower setting bandages (five to eight minutes) appeared to stand up better than the others. This is in agreement with laboratory data on the compressive strength of the experimental bandages. Although the method of wrapping the bandages for the strength test does not exactly duplicate their clinical use, comparative values have been obtained which correlate very well with clinical data in this and other clinical studies (see Table IV).

Most bandages require up to seven days after their application to attain their ultimate cast strength, depending on environmental conditions. The increase of cast strength with time under normal conditions of humidity and temperature is shown in Fig. 4 for a typical bandage. It is apparent that this cast has not reached its full strength after 24 hours. After 48 hours the strength of the cast approaches much more closely the ultimate value. This observation has importance with respect to walking casts. The advantage of delaying the period before allowing the patient to walk on a cast is thus illustrated experimentally.

It has already been pointed out that the composition of a bandage has a great deal to do with determining its cast strength and setting time.

TABLE IV.—CORRELATION OF LABORATORY AND CLINICAL DATA

Bandage type	*Compressive strength after 24 hours*	*Breakdowns reported*
1	90 lb.	25%
2	140 lb.	10%
3	200 lb.	6%

However, the conditions employed by the surgeon during application also greatly affect both cast strength and setting time of the bandage. For example, as the temperature of the water into which the bandages are dipped is increased, the setting time is decreased (see Fig. 5).

The amount of working the plaster receives while the doctor is moulding and shaping the cast also affects its strength and, in a minor way, its setting time. Generally, the plaster should be worked sufficiently to ensure adequate fusion

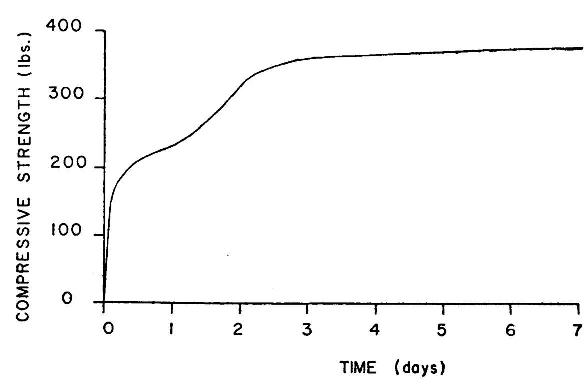

Fig. 4.—Variation of cast strength with time.

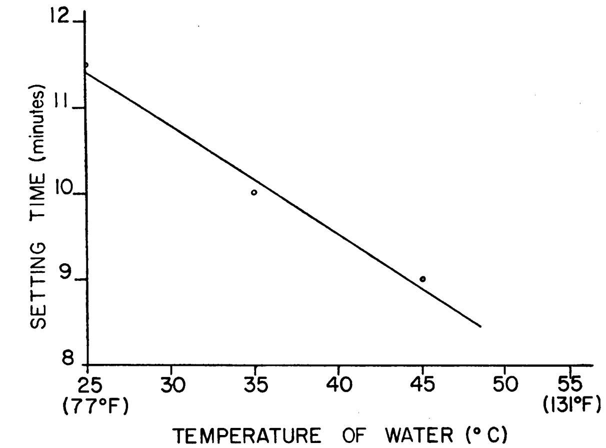

Fig. 5.—Effect of water temperature on setting time.

of the bandage layers and proper moulding to body contours, but disturbance of the plaster should be avoided after the critical phase in the setting process. Bending or otherwise disturbing the plaster in a region after this critical phase results in a weakening of the cast in this area, leading sooner or later to cast breakdown.

The importance of the plaster-water ratio in determining the hardness and compressive strength of plaster of Paris has been reported for surgical,[3] dental,[4] ceramic,[5] and structural purposes. Chassevent[7] has commented that poor plaster work is generally due to an excess of water during setting. Kaufmann[8] has derived equations relating the compressive strength to

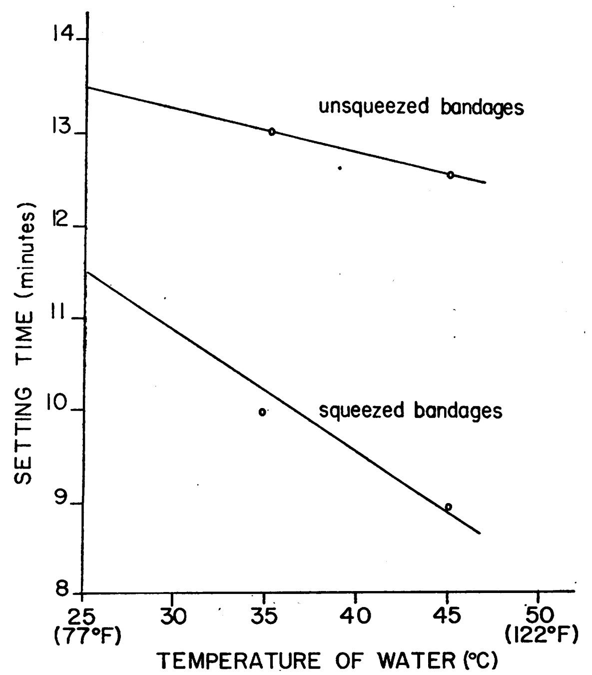

Fig. 6.—Effect of excess water in bandages on setting time.

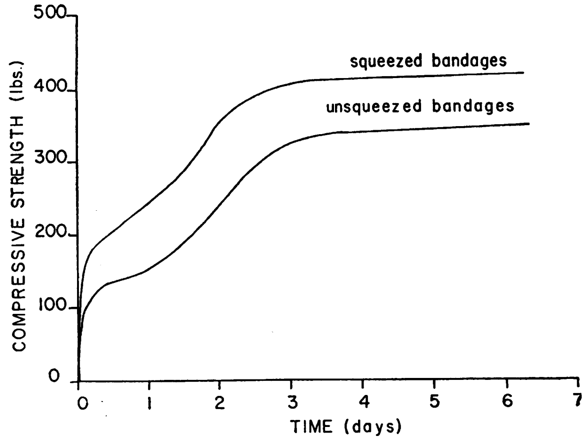

Fig. 7.—Effect of excess water on the strength of casts.

water content. Chassevent and Domine[6] have offered an explanation for the decrease in mechanical resistance in terms of increased separation of crystals and the presence of a polar liquid layer around the crystals. Generally, these and many other authors agree that as the amount of water is increased over that required for the setting process, the strength of the plaster of Paris decreases.

The amount of water left in a plaster of Paris bandage depends largely on the orthopædic surgeon's technique. Generally, there are two extreme types of orthopædic surgeons—the "squeezers" and the "non-squeezers". Most of the surgeons in Canada seem to be closer to the non-squeezing type. Our experimental work suggests that a moderately firm squeeze is desirable, in a manner tending toward the "squeezer", but the bandages should not be wrung out.

Referring once again to the chemical equation, it can be seen that only one and one-half parts of water are required for each part of plaster of Paris. Thus, in order to get a good crystal structure, the excess water should be removed from the bandage. Although several of the surgeons observed in this study squeezed their bandages lightly, few removed much of the excess water.

The effect of squeezing a bandage on its setting time is shown in Fig. 6. A squeezed bandage sets more quickly than one which has not been squeezed. Of greater importance is the effect of squeezing a bandage on its cast strength. A graph of compressive strength of a cast versus time for squeezed and unsqueezed bandages is shown in Fig. 7. For a bandage low in plaster loss, squeezing results in faster attainment of cast strength and higher ultimate cast strength. Regardless of the type of bandage, squeezing results in more rapid attainment of cast strength. Rapid attainment of strength is important because most cast failures result from damage to the cast during the early hours after application.

Several surgeons noted that on hot humid days, casts made from these bandages did not appear as strong. A squeezed bandage exposed to high humidity during drying has a cast strength very close to the curve for unsqueezed bandages. Humid conditions during drying may affect ultimate cast strength as well as rate of attainment of cast strength. This suggests an even greater need for removal of excess water in humid weather.

A squeezed bandage is not as messy to use as one in which excess water has been left. Less plaster falls from the bandage during application and less plaster is left on the surgeon's hands. As a result, more plaster is retained in a cast from a squeezed bandage than from one that is not squeezed. This is particularly true of bandages containing a binding agent.

SUMMARY AND CONCLUSIONS

1. The properties of a plaster of Paris bandage vary with the ingredients in the plaster and the technique of application used by the surgeon.

2. The properties desired by Canadian orthopædic surgeons varied with the individual but generally they favoured extra-fast setting bandages (two to five minutes), especially for small casts. The fast setting bandages (five to eight minutes) were still considered highly satisfactory by many observers, particularly for large casts. This would suggest that plasters with both extra-fast and fast setting times should be available.

3. The doctor can control the setting time by increasing the temperature of the water used or by reducing the amount of water left in the bandage by squeezing it.

4. The strength or durability of a plaster of Paris cast is perhaps its most important property. Of prime importance is the rate of attainment of this cast strength. A great number of cast failures result from damage to the cast during the first 24 hours. A high cast strength is, therefore, very desirable during this period. Removal of excess water by squeezing the bandage results in a more rapid attainment of strength and should lead to fewer cast breakdowns, provided there is no large plaster loss.

5. The orthopædic surgeons taking part in this study talked more of "feel" and setting time than of cast strength. The bandages were satisfactory from the cast strength standpoint even though a breakdown rate of 10% was recorded. The full potential cast strength of the experimental bandages was not realized due to the techniques used in their application. Perhaps too much emphasis has been placed in Canada on the "feel" of bandages, and not enough on ultimate cast strength and its rate of attainment.

It is a pleasure to acknowledge the assistance of the Canadian orthopædic surgeons, without whose help this paper could not have been written.

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RÉSUMÉ

Les propriétés d'un appareil plâtré varient d'après les ingrédients qui entrent dans la composition du plâtre ainsi que d'après la technique de l'application par le chirurgien. Un grand nombre de modifications furent apportées à la formule depuis 1852 alors que Matthysen en proposa l'emploi pour éclissage. Les orthopédistes de 12 hôpitaux canadiens appelés à se prononcer sur les qualités les plus importantes exigées d'un plâtre, déclarèrent qu'ils tenaient surtout à des compositions qui sèchent rapidement (de 2 à 5 minutes) pour les petits plâtres. Certains d'entre eux se dirent satisfaits d'employer des compositions séchant entre 5 et 8 minutes pour les grands appareils. Les deux genres devraient donc toujours être fournis. L'applicateur peut modifier le temps de prise en élevant la température de l'eau ou en essorant l'excédent d'eau gâchage. La résistance du plâtre est peut-être sa propriété la plus importante, et un aspect fondamental de cette propriété est la durée requise pour l'atteindre.

Les avaries infligés au plâtre dans les premières 24 heures rendent souvent les appareils défectueux. Le meilleur moyen d'obtenir une rigidité satisfaisante en un minimum de temps (qualité particulièrement nécessaire dans cette période) consiste à exprimer l'eau des bandages en les comprimant, (*vide supra*) prenant soin tout de même de ne pas perdre trop de plâtre en ce faisant. Les orthopédistes consultés dans cette enquête semblèrent plus préoccupés du maniement et du temps de prise du plâtre que de la résistance des appareils. En dépit d'une casse de 10% dans les 612 appareils sur lesquels est basé ce rapport, les compositions de plâtre présentées pour évaluation furent passées comme satisfaisantes.