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THE RELAXATION OF SOME ACRYLIC BONE CEMENTS

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The creep and relaxation of acrylic cements during conditions simulating the conditions in the acetabulum have been examined. CMW and Simplex were found to reach stresses of about 10 N/cm^2 after 1 year whereas Palacos had lost most of its stress after 6 weeks.

Key words: bone cement; hip joint prosthesis

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The problems of loosening of acetabular components in total hip replacement are gaining importance. The details of how the acrylic cements transfer forces from the acetabular component of a total hip replacement to the bone are not well understood, but in a previous article (Holm 1980) the author has shown that acrylic cements may generate total stresses between the anchoring holes drilled into the acetabular bone of up to about 1000 N, mainly because of contraction when cooling. It is well known that plastics will creep and undergo relaxation under load, i.e. plastic deformation occurs with time. The present investigation is an attempt to evaluate the speed of creep and relaxation of some acrylic cements.

MATERIAL AND METHODS

Three brands of cement were tested, CMW Bone Cement*, Surgical Simplex*, and Palacos R*. The apparatus and experimental setup has been described in detail in a previous paper (Holm 1980). It consisted of a measuring device in which the linear contraction of methylmethacrylate was evaluated by measuring the deformation of a U-shaped spring. The acrylic specimen was moulded across the open end of the "U" and allowed to contract. The relaxation was then measured under a slowly decreasing load as the U-spring regained its original shape. The test pieces for the present experiment were all 20 × 8 mm and the distance between anchoring points was 26.5 mm. The cement was mixed at room temperature (22°C) by hand according to the manufacturers' instructions and placed in the mould to obtain the correct dimensions. The initial deformation, i.e. linear shrinkage, was measured with a dial gauge from which further daily readings were taken. Two samples of CMW were tested as well as two of Simplex and one of Palacos R. One long-term experiment was conducted with CMW. The individual experiments were continued for about 3 weeks whereas the long-term experiment lasted 3 months. All experiments were carried out in distilled water at 38°C.

The standard method of testing creep involves loading the test piece in tension with a constant stress and expressing the elongation as a function of time. A relaxation test is made by straining a given test piece to a given length in tension or compression and measuring the stress as it falls towards zero. In the present experiment the relaxation of the cement is evaluated by a test with very small values of strain and a slowly decreasing value of stress. It is thus a compromise between a creep and a relaxation test. This method was chosen in order to get an estimate of the time factor involved when the cement is anchored to the bone where the stress will decrease as the cement creeps.

The creep of a plastic material can be expressed by the formula:

$$\varepsilon = \varepsilon_0 + mt^n \text{ (Schreyer 1972)} \qquad (1)$$

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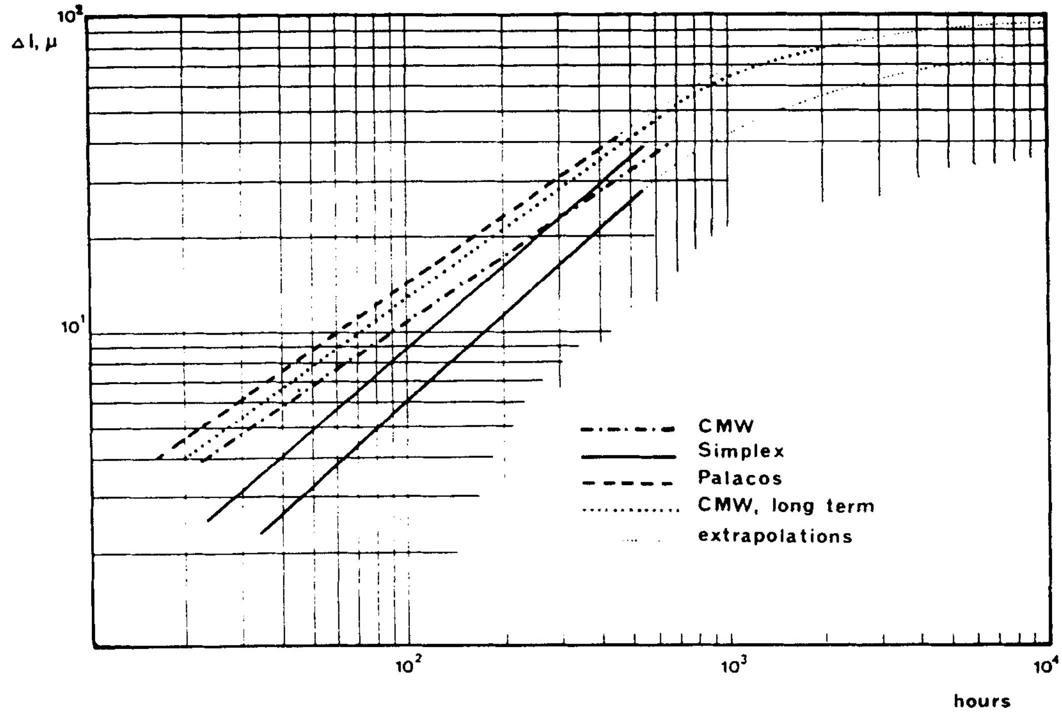

Figure 1. Creep of some acrylic cements. Double logarithmic presentation with extrapolations.

ε = strain at a given time. ε_0 = strain at the time = 0. ε_0 thus is the strain which occurs immediately upon loading, i.e. basically the elastic strain. m and n are material constants. m is a temperature dependent constant and on the graph it will be the projection to the time = 1. n is the inclination of the line and is independent of the stress. The equation $\varepsilon = \varepsilon_0 + mt^n$ can be transformed to $\varepsilon - \varepsilon_0 = mt^n$, and in logarithmic form we have:

$$\ln(\varepsilon - \varepsilon_0) = \ln m + n \times \ln t \quad (2)$$

which is a useful expression for a double-logarithmic presentation.

In the present experiment the elongation, Δl, was measured directly and was used instead of the strain.

ε_0 was difficult to determine with accuracy as the test piece had been under stress for some time before the first reading could be taken. In other words, an exact starting time could not be determined because of the continuous nature of the polymerization process. Furthermore $_0$ is based on the condition of constant stress whereas the stress in the present experiment, as in the acetabulum, was decreasing with time. In the calculation, therefore, Δl is substituted for $\varepsilon - \varepsilon_0$, as $\varepsilon - \varepsilon_0 \times 26.5$ mm $= \Delta l$.

This means that the values obtained for m are only valid for a distance between anchoring points of 26.5 mm and are therefore of minor interest, whereas the n-value which is independent of stress is the important figure.

RESULTS

The results are shown graphically in Figure 1. Figure 2 shows the percentage relaxation in the five experiments. The values of m and n were calculated by linear regression and are given in Table 1 together with the coefficients of correlation, the maximum linear shrinkage, the percentage relaxation, and the shrinkage at 500 hours, Δl $\Delta l_{max} - \Delta l_{500}$. Special consideration will be given to the second set of values in the long-term experiment.

The first observation to be made is that the mathematical expression is valid as shown by the coefficients of correlation even though the formula is designed to describe a regular creep

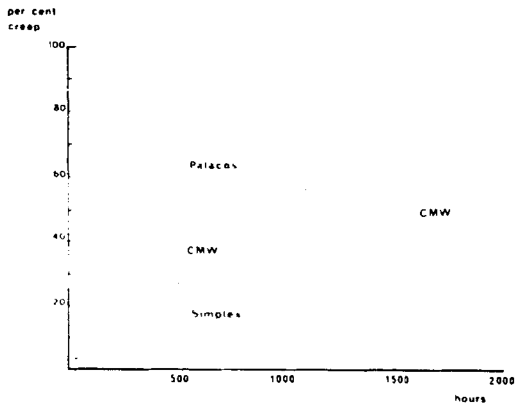

Figure 2. Percentage creep of some acrylic cements.

test. This holds true up to about 500 hours. The primary linear shrinkages were not different from those previously reported (Holm 1980), i.e. approximately the same values were obtained for CMW and Simplex and a considerably lower value for Palacos. Also Palacos showed an m-value which was about twice the value for the two other brands. These two factors, a high m-value and a low linear shrinkage, account for the rapid relaxation of Palacos of 68 per cent in 500 hours as compared with 20 per cent for Simplex and 30 per cent for CMW. The n-values which represent the inclination of the lines in Figure 1 do not vary greatly and are between 0.7 and 0.8. The lines are therefore almost parallel. The long-term experiment with CMW shows that the cement no longer follows the mathematical expression after about 500–550 hours. As will be seen from the graph the curve levels off indicating that the relaxation proceeds much more slowly as the stress decreases. A new n-value has been calculated which demonstrates the extension in time. This n-value will only be valid up to about 2000 hours. After this time the n-value decreases further, but at that time the experiment was discontinued. At 2000 hours about two-thirds of the shrinkage had relaxed and the stress in the test sample at this time could be calculated to be

$$\frac{0.058 \text{ mm} \times 554 \text{ n}}{1.6 \text{ cm}^2} = 20 \text{ N/cm}^2.$$

The m-value for this section of the test is a theoretical extrapolation and is of no interest.

DISCUSSION

As shown in a previous paper (Holm 1980) methylmethacrylate, when used in fixation of acetabular components with anchoring holes, creates considerable forces which contribute to the fixation of the cup. As plastics are known to creep it is important to know the length of time the forces are present. The relaxation and creep of acrylics have been fairly well investigated (Schreyer 1972). A number of factors make the evaluation of acrylic cements complicated. Commercial acrylics such as Plexiglas® show a creep of about 1 per cent per year under standard conditions.

Several factors will, however, increase this factor. The temperature has a definite influence; creep increases when the temperature increases. Another factor which

Table 1. Calculated values for n and m, coefficient of correlation, maximum linear shrinkage, shrinkage at 500 h, and the percentage creep/relaxation at 500 h

	n	m	Coefficient of correlation	Δl_{max} mm	$\Delta l_{max} - \Delta l_{500}$ mm	Per cent relaxation at 500 h
CMW 1	0.7	0.4	†.98	0.094	0.062	34
CMW 2, 500 h	0.8	0.3	0.99	0.145	0.104	28
CMW long-term 500 h	0.5	(2.1)	0.99	0	0.058 (2000 h)	60 (2000 h)
Simplex 1	0.8	0.1	0.98	0.132	0.106	19
Simplex 2	0.8	0.3	0.98	0.134	0.108	19
Palacos R	0.7	0.7	0.99	0.068	0.025	62

greatly increases the speed of creep is humidity.

Creep and relaxation are simply two ways of describing the same phenomenon. The mechanism which is at work consists of a stretching and realignment of molecules which is greatly facilitated by the presence of water which acts as an internal "lubricant". As shown by Ohnsorge & Grötz (1974) acrylic cement will absorb 1.3 per cent by volume of water, which accounts for a part of the creep. To these variables are added the degree of polymerization of the cement, i.e. the length and branching of the molecules, and the amount of air incorporated in the cement during mixing.

The present results comply well with the general knowledge of relaxation and creep (Schreyer 1972). At the termination of the experiments there was still considerable stress in the CMW and Simplex samples whereas Palacos had lost most of its stress. The results may be extrapolated forwards in time, but the estimates will contain considerable uncertainty. It seems reasonable to assume that all acrylic cements behave in a similar manner and it will be seen from Figure 1 that the curves are asymptotic. An estimate of the time when the stress has reached 10 N/cm^2 (=0.03 mm shrinkage) can be made from the graph. This will show that the time for CMW will be of the order of magnitude of $1-2 \times 10^4$ hours = 1–2 years. The time for Simplex is difficult to evaluate, but it will not be shorter, rather the opposite as it shows only 20 per cent relaxation at 500 hours. For Palacos, the time will be considerably shorter, the graph would indicate less than 1000 hours.

The physical behaviour of acrylic bone cement has clinical significance in terms of mechanical fixation and loosening. Immediately following polymerization the cement has a grip on the bone of 500–1000 N (CMW, Simplex). This force counteracts the forces of friction. As it decreases with time friction prevails and mechanical loosening may start.

The behaviour of bone in terms of relaxation and creep is difficult to evaluate. In fact, when loaded in compression creep is not to be expected when the composition of this composite biological material is considered. The compression forces will be sustained by the apatite crystals in the bone and this substance cannot be expected to undergo creep. If a plastic deformation were to occur it would come from remodelling as long as the loads are within the tolerances of the bone. Hert et al. (1969) have shown that a static load on bone causes no discernible remodelling. Perren et al. (1969) measured the strain in the compression plates used in the fixation of osteotomies and found decreasing strain with time, but their results are not directly applicable in the present context as they were measuring the strain with an osteotomy between the measuring points. Such a situation does not exist in the acetabulum where the anchoring holes are placed through otherwise basically intact cortical bone.

It is evident that any remodelling or resorption of bone at the edges of the anchoring holes in the acetabulum will rapidly decrease the cement forces, and in cases where the cement for some reason has to be set in cancellous bone no stress and therefore no relaxation can be expected.

CONCLUSION

The acetabular component of a total hip replacement when fixed by means of anchoring holes for the cement in the acetabular corticalis is held in place by the contraction forces of the cement for a certain period of time. The speed with which the acrylic compound undergoes relaxation is dependent on the type of cement – Palacos creeping much faster than CMW and Simplex – and on the response of the bone.

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