Heat conduction in acrylic bone cement : a thermodynamical analysis

Heat conduction in acrylic bone cement; a thermodynamical analysis.

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Heat production of self-curing acrylic bone cement, as used for fixation of implants in orthopaedic surgery, may lead to high temperatures in bone tissue and subsequently to bone necrosis.
A computer programm was developed for calculation of non-steady temperature fields in heat producing structures of different materials, like implant, cement and bone. This programm is used to analyse the heat conduction problem in vivo. It is based on a finite element solution technique of the thermodynamical differential equations.

λ	thermal conductivity	J/sec.°C.m	for all materials involved
ρ	density	kg/m^3	
c	specific heat	J/kg.°C	
ρ_m	density of MMA	kg/m^3	
γ_v	PMMA/MMA ratio cement	m^3/m^3	
Q_t	Heat prod./kg MMA	J/kg	
τ	polymerization time	sec	
T_o	begin temperature	°C	all mat.
T_u	ambient temperature	°C	
p(t)	generalized polymerization curve		

Table 1

The input of the programm is formed by a description of the 3-dimensional geometry of the structure and the relevant properties of the materials, listed in table I. It is assumed that these properties are independent of temperature.

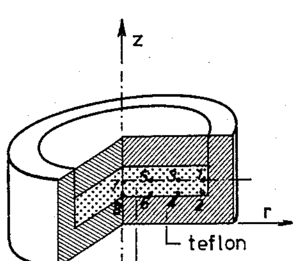

Fig.1

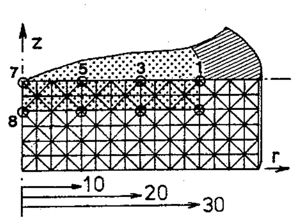

Fig.2

The method was tried for a structure formed by a teflon cup, filled with acrylic cement (fig.1). Meyer et al. [1] measured temperatures in a similar experimental set up (numbers 1 through 8 refer to their measurement points); with these experimental data the calculated results are verified. Fig.2 shows the element mesh.
Fig.3 shows the temperature development in time, as calculated with 4 different polymerization curves (p(t) = % polymerized MMA as function of time).
The pol.curve no.4, that gives the best results compared to Meyer et al., was derived from our own measurements. Value for other properties were taken from literature.
The power of the method presented, lies in the possibilities to analyse the effects of the important material and geometrical properties on the temperatures. Examples of such sensitivity analyses are showr in fig.3, with regard to the polymerization curve, in fig.4 with regard to the r-coördinate (maximum temperatures in the middle and in the interface plane) and in fig.5, with regard to the thermal conductivity of the cement (temperature development in point no.8). Similar analyses are presented for other properties.

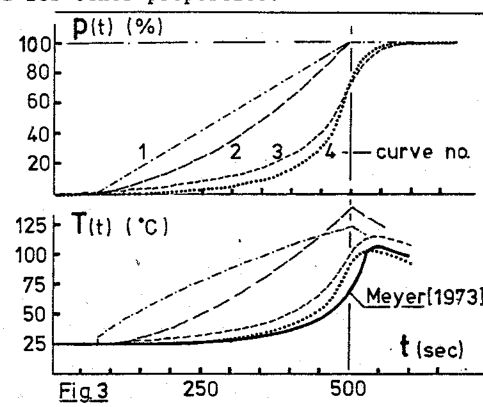

Fig.3

It is found that some properties affect mainly the value of the maximum temperatures, some the time interval in which the temperature is higher than a certain value and others affect both.

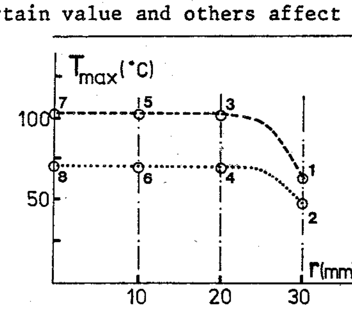

Fig.4

The results of these and similar analyses on implanted bone cement, are used to develop criteria for modifications and implantation techniques of the cement.

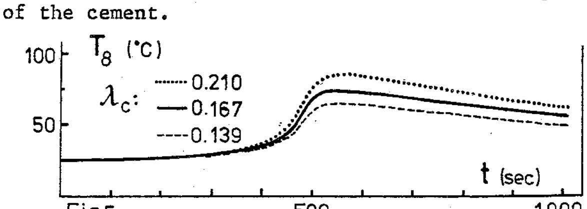

Fig.5

Ref.: [1] Meyer, J.R.; Lautenschlager, E.P. and Moore, B.K., (1973); On the setting properties of acrylic bone cement; J.Bone Jt. Surg. 55A. pp.149-156.