

# Variations of temperature of acrylic bone cements prepared by hand and vacuum mixing during their polymerization

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The aim of this work was to investigate variations of temperature in acrylic bone cement SmartSet HV during its polymerization as the function of mixing technique (hand mixing and vacuum mixing) and sample thickness. The temperature of 25-mm diameter samples differing in their thickness was monitored using a parallel plate measuring system of the compact rheometer preheated to the body temperature. The curves representing the temperature measured and average values of times needed to obtain the peak temperatures of the test samples prepared by different techniques of mixing are presented and discussed. It was found that the maximum temperature and also the times of peak temperatures rose with sample thickness but at different rate for each technique of mixing.

*Key words: bone cement, polymerization, thermal polymerization, thermal characteristics*

## 1. Introduction

Self-curing acrylic bone cement has been used in orthopedic surgery for more than 40 years. Sir John Charnley introduced it for the fixation of prosthetic components to bone in total hip arthroplasty. Since then the prostheses based on acrylic cement have been designed for almost all types of joints [1]. They have different chemical formulations giving a range of cements with varying handling characteristics required for broad range of clinical and surgical techniques.

Acrylic cement is not only a reasonably strong in compression, but also a relatively brittle material, which makes it susceptible to fracture as a result of tensile stresses. The long-term behaviour of the cement mantle depends on the mechanical properties of the bone cement and on how it is stressed in vivo [2], [3]. It was shown that the method used to mix the liquid monomer and powder of polymethylmethacrylate (PMMA) bone cement influences both physical prop-

erties and quality of the cement. Reducing bone cement porosity by vacuum mixing has been shown to lower the risk of revision compared to manual mixing [4].

The primary function of the bone cement is to provide a stable interface between prosthetic implant and the surrounding bone and load distribution from the prosthetic implant to the surrounding tissues [1], [5], [6].

Two basic substrates, i.e. a polymer powder and liquid monomer, form the cement bond. The mixing of the two components and getting viscous dough are followed by a progressive polymerization of the liquid monomer to a solid mass [5]. This allows handling, forming, and delivery of the cement into the bone canal.

Bone cement was mixed first using a spatula and bowl, which can be responsible for a high degree of porosity of the cement structure; also the person mixing the cement was exposed to a high level of methylmethacrylate vapours which are noxious [7]. Nowadays, cement is mixed under an increased vacuum (> -86 kPa) to improve its quality by reducing the quantity of bubbles in the cement structure and to

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reduce the level of monomer fumes discharged into environment. The cement is mixed and transferred within the mixing barrel, thus there is no human contact with it. The prosthesis is then introduced into the viscous dough and held in place while it solidifies by the exothermic polymerization of the liquid monomer. During the exothermic polymerization a large quantity of heat is generated [8]. The exposure of bone to high temperatures in some cases has led to incidences of bone necrosis and tissue damage, ultimately resulting in failure of the prosthetic fixation. The higher the temperature, the shorter the exposure duration before thermal bone necrosis occurs [1], [8].

Over the last years there have been several studies conducted in order to investigate the thermal characteristics of acrylic bone cement. Many authors have commented on the temperature problem induced by the curing of polymethylmethacrylate (PMMA) cement mass. DiPISA et al. [8], [9] are of the opinion that the temperature at the bone–cement interface is a function of:

- the quantity of heat produced by the bone cement,
- the rate at which the heat is produced,
- the thermal conductivity and thermal capacity of the bone, prosthesis and cement,
- the initial conditions of the bone/cement prosthesis system, including initial and ambient temperatures,
- the preparation of the cement [8], [9].

MEYER et al. [10] found that the maximum temperature was 107 °C for a 10-mm cement mantle. SIH et al. [11] showed that for a cement thickness of 5 mm the temperature reached 56 °C and for a cement thickness of 6–7 mm, 60 °C. LUNDSKOG [12] indicated that heating a bone tissue to 50 °C for 1 minute or to 47 °C for 5 minutes is responsible for the malfunction of bone becoming resorbed and replaced with fat cells. He also observed that a bone heated to 47 °C for 1 minute causes a fat cell injury [12]. This implies that 47 °C is the threshold temperature for the occurrence of morphologically evident bone tissue damage.

## 2. Experimental

### 2.1. Composition of bone cement

As an experimental material the acrylic self-curing high viscosity bone cement SmartSet HV was used. It is suitable for both hand and vacuum mixing. Its quantitative composition is specified in table 1.

Table 1. Quantitative composition (in w/w %) of SmartSet HV bone cement

Powder	Methylmethacrylate/ methylacrylate copolymer	84
	Di-benzoylperoxide	1
	Zirconium dioxide	15
Liquid	Methylmethacrylate	97.5
	<i>N,N</i> -dimethyl- <i>p</i> -toluidine	≤ 2.5
	Hydroquinone	0.0075

### 2.2. Sample preparation

The cement samples were prepared by hand and vacuum mixing technique, both with exact timing. After the mixing process the dough was put into the rotational rheometer Physica MCR301 with parallel plates whose diameters were 25 mm. Plates were preheated to 37 °C to simulate in vivo conditions. The samples were trimmed to 1, 2, 4 and 5 mm height (the optimal cement mantle thickness in vivo is 2–5 mm). Straining option was omitted during the measurements, only the surface temperatures of the trimmed samples were monitored in the chamber with constant temperature of 37 °C.

Powdered component was poured into a suitable, dry, clean ceramic bowl and then liquid component was added and both were mixed by hand. The dough was mixed for 30 seconds very carefully to minimize the air entrapment. When the dough was formed there was a need to wait for next 60 seconds (waiting time) for this type of cement. Then it was taken into hands and kneaded for a few seconds before inserting to the rheometer.

For vacuum mixing the CEMVAC syringe mixing system was used. After 90 seconds from the beginning of mixing, the syringe system with included cement was transferred into a suitable application gun from where the cement mass was ready to be placed in the rheometer.

### 2.3. Results

Because of a possible inhomogeneity of the prepared cement mass, 4 measurements of temperature versus time were done for each sample thickness. The curves representing the surface temperature measured in 1, 2, 4 and 5 mm thick hand-mixed samples are shown in figures 1–4 and the curves representing the temperature changes in vacuum-mixed samples can be seen in figures 5–8. Average values of temperature peaks and the respective average times for hand-mixed samples and for vacuum-mixed samples are given, respectively, in tables 2 and 3.

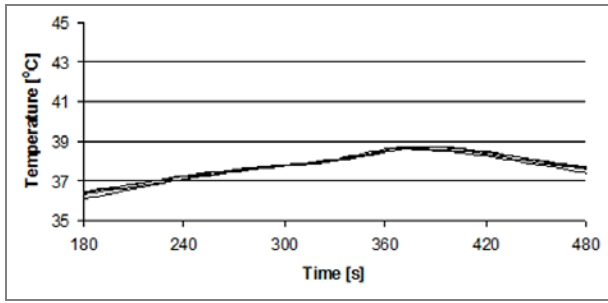


Fig. 1. Temperature changes of 1-mm thick samples prepared by hand mixing

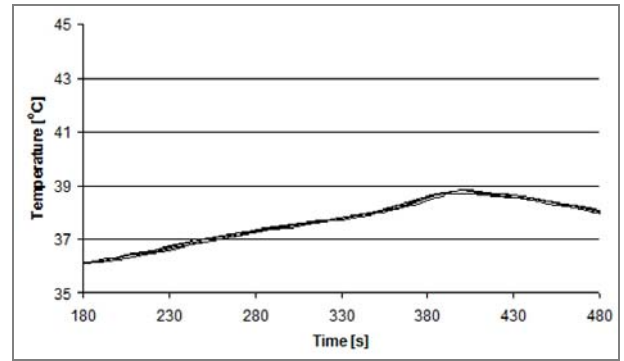


Fig. 5. Temperature changes of 1-mm thick samples prepared by vacuum mixing

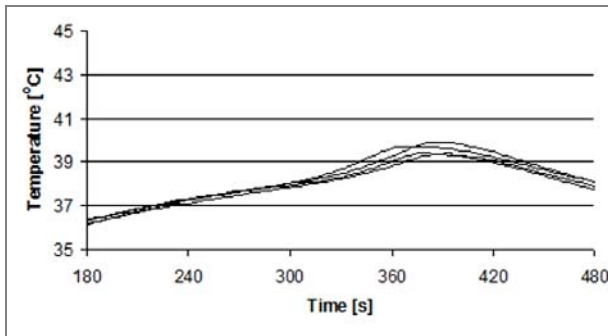


Fig. 2. Temperature changes of 2-mm thick samples prepared by hand mixing

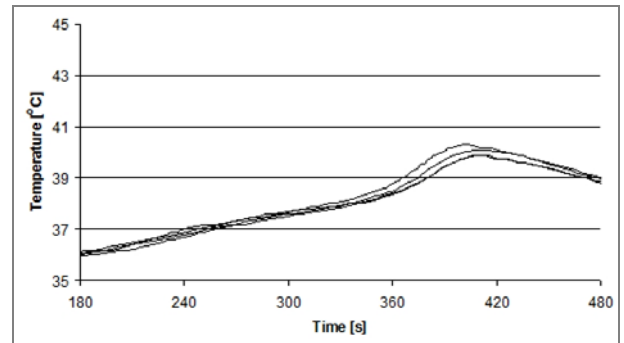


Fig. 6. Temperature changes of 2-mm thick samples prepared by vacuum mixing

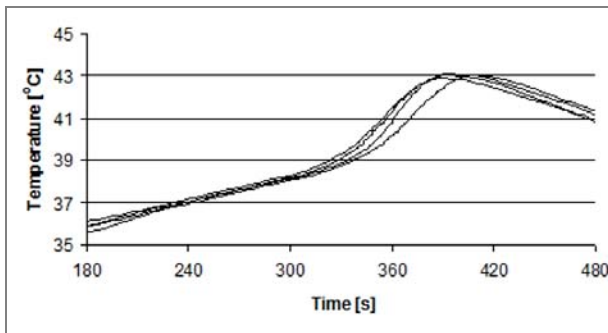


Fig. 3. Temperature changes of 4-mm thick samples prepared by hand mixing

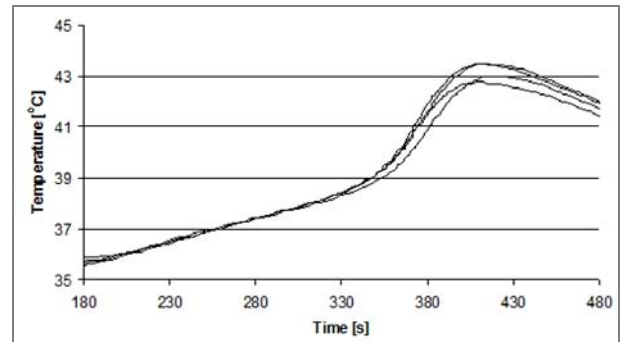


Fig. 7. Temperature changes of 4-mm thick samples prepared by vacuum mixing

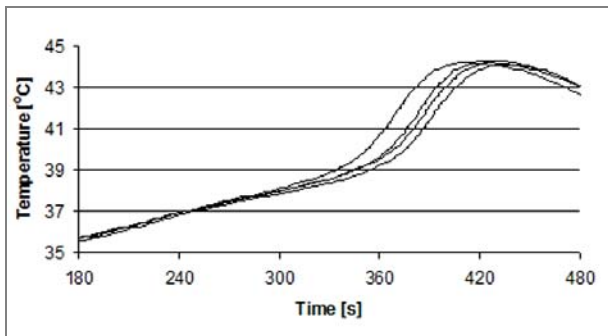


Fig. 4. Temperature changes of 5-mm thick samples prepared by hand mixing

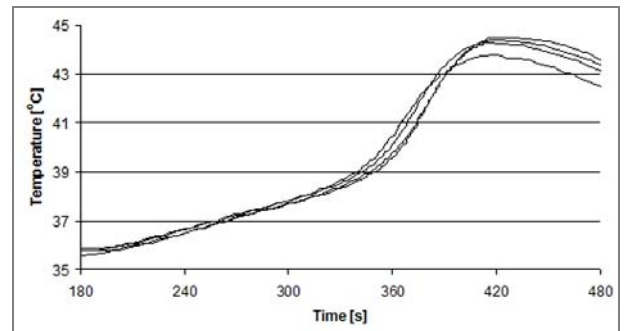


Fig. 8. Temperature changes of 5-mm thick samples prepared by vacuum mixing

Table 2. Maximum measured temperatures and respective times for differently thick cement samples mixed by hand

Thickness 1 mm		Thickness 2 mm		Thickness 4 mm		Thickness 5 mm	
(°C)	(s)	(°C)	(s)	(°C)	(s)	(°C)	(s)
38.7	383	39.4	395	43	406	44.1	429
38.6	363	39.9	385	43.1	391	44.2	408
38.7	373	39.4	377	43	391	44.3	422
38.6	373	39.7	365	42.9	389	44.2	423
<b>38.65</b>	<b>373</b>	<b>39.6</b>	<b>381</b>	<b>43</b>	<b>394</b>	<b>44.2</b>	<b>421</b>
±	±	±	±	±	±	±	±
<b>0.03</b>	<b>4</b>	<b>0.12</b>	<b>6</b>	<b>0.04</b>	<b>4</b>	<b>0.04</b>	<b>4</b>

37 °C, while the instruction leaflet for surgeons gives the clinical timing at 19, 23 and 26 °C and does not consider the real in vivo operation conditions.

During the polymerization the pattern of temperature increase to the maximum value is different for each cement thickness, which is caused by low thermal conductivity of PMMA ( $0.18 \text{ W m}^{-1} \text{ K}^{-1}$ ) [13]. When surface temperatures of coarser samples were measured, it became evident that heat released in their middle parts was transported to the measuring system later than in the case of thick samples.

Table 3. Maximum measured temperatures and respective times for differently thick cement samples mixed by vacuum

Thickness 1 mm		Thickness 2 mm		Thickness 4 mm		Thickness 5 mm	
(°C)	(s)	(°C)	(s)	(°C)	(s)	(°C)	(s)
38.8	400	39.9	412	43.5	411	44.4	418
38.8	400	40.1	410	43.5	410	44.5	418
38.7	395	39.9	414	42.8	412	44.3	412
38.7	391	40.3	402	43	414	43.8	420
<b>38.75</b>	<b>396.5</b>	<b>40.05</b>	<b>409.5</b>	<b>43.2</b>	<b>411.8</b>	<b>44.25</b>	<b>417</b>
±	±	±	±	±	±	±	±
<b>0.03</b>	<b>2.18</b>	<b>0.1</b>	<b>2.63</b>	<b>0.18</b>	<b>0.85</b>	<b>0.16</b>	<b>1.73</b>

## 2.4. Discussion

Before the measurements the measuring system of the rheometer was preheated to 37 °C, but opening the chamber, positioning and trimming the samples caused drop in the set temperature of the system. In spite of this fact, temperature was close to in vivo temperature (35.5–36.1 °C).

From the results obtained it can be clearly seen that the amount of the heat produced during the exothermal cement polymerization depends on the sample thickness: the coarser the sample, the higher the peak temperature in polymerization process and temperature rises at different rate. The differences between the peak temperatures of hand- and vacuum-mixed samples of the same thickness are negligible. This means that the technique of mixing has not any effect on the amount of the heat produced during the irreversible polymerization process.

The times measured for different techniques of mixing, when cement mass reaches its maximum (peak) of temperature, differ significantly. Our results, except the case where the sample thickness was 5 mm, do not support the theory that vacuum mixing and syringe application reduce the working and hardening time of the tested bone cement. It could be due to the selected measuring conditions; exactly, the relatively high initial temperature of measuring system is close to

The highest calculated mean value of peak temperature under the selected conditions was  $44.25 \pm 0.16$  °C for 5-mm thick samples, which according to [12] cannot cause bone and tissue destruction. A drop in temperature after cements solidifying is regular. Heat removal from the steel plates is controlled by the constant surrounding air temperature of 37 °C, and the heat conductivity of air is low.

## 3. Conclusions

- The technique of mixing has no effect on the amount of heat produced during the polymerization of bone cement.
- The time shift of the temperature peaks of curing processes for differently thick cement samples is caused by low thermal conductivity of the cement mass. The polymerization heat from the centre of sample has to be transported through the cement mass to steel plates where the temperature is measured.
- According to our results, maintaining the maximum optimal cement mantle thickness at 5 mm cannot cause thermal necrosis of bone cells and the surrounding tissues.

• For an exact explanation of the temperature and time measurements it is necessary to closely attend to chemical and physical processes during the polymerization of the bone cement tested under similar conditions.

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