Experimental Research Regarding the Thermomechanical Behaviour of PMMA During Recovery of Patients with Joint Replacements

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Most studies and experimental tests performed upon orthopaedic bone cements are related to their use in everyday conditions when usual wears are due to compression and fatigue. The present paper deals with some special situations occurred during the patient's recovery after the surgery. The recovery activities and motions may induce different types of loads, like tensile, during stretching and relaxation techniques, especially in the joint insertion area. These situations are insufficiently researched, but they represent one of the main concerns of the medical staff involved in recovery and rehabilitation. Besides the study of mechanical properties for these special situations the paper proposes also a thermal analysis during preparation of the polymethylmethacrylate(PMMA) as it can be the trigger of serious health issues (necrosis, blood circulation problems, BCIS, etc.) due to the exothermic polymerization reaction. The monitoring method proposed for the temperatures developed during the polymerization may avoid the aforementioned issues.

Keywords: Polymethylmethacrylate (PMMA), tensile, recovery, bone cement, joint replacement

Joint replacement has become a fairly regular surgery nowadays as the people's lifespan has increased due to the exponential technological achievements in medicine. A successful outcome for a joint replacement does not depend only on the medical staff skills and medical equipment progress but also on the thorough research of the orthopaedic materials properties. Most studies concerning orthopaedic materials properties deal with the most encountered types of loadings, especially compression and fatigue [1], which may affect the interface between cement and bone [2]. The long-term success of cemented replacements are threatened by mechanical failure [3] of the bone cement mantle as one of the most common causes of the reconstruction loosening and the reasons leading to such an unfortunate outcome may be also due to special situations. One of these situations occurs during recovery activities, which are mandatory after any joint replacement. Stretching and relaxation techniques by kinetotherapy induce traction loads upon the insertion surface of the prosthesis and can produce damage to the prosthetic cement if certain stresses are reached (35.4 MPa).

The investigations made at the Emergency Hospital in Brasov revealed the fact that the traditionally used material for joint replacements is for many years an acrylic cement (PMMA). The success rate is high (around 90%) but still there are issues to be addressed [4], one of them being the risk of tissue necrosis, fibrosis and other impairments [5] due to the exothermic polymerization reaction produced during the material preparation.[6] After curing there is always a residual amount of monomer (MMA) which decreases within 2 or 3 weeks but a part still enters the blood circulation producing negative effects and rarely leading to patient's death [7].

Also further medical studies must certify increased compliance between cement and patient skin [8,9].

Experimental part

The interdisciplinary team consisting of both doctors and engineers approached the aforementioned issues, concentrating their efforts on the most used bone cement polymethylmethacrylate (PMMA).

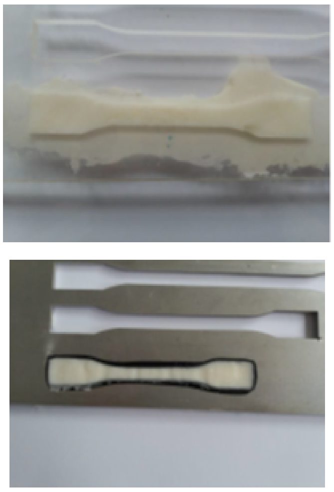

Fig.1 Moulds for specimens manufacturing

The first stage was the design and manufacturing of some specimens according to the standards in force. The specimens were designed in CAD software and manufactured according to the F-2118 standard using Plexiglas and aluminium moulds, as shown in fig.1a and b.

The material was prepared according to the instructions, monitoring also the exothermic radical polymerization reaction which may cause BCIS (bone cement implantation syndrome) leading to intra-operative mortality ranging from 0.02% to 6.6% of the cases [10], necrosis or impairment in blood circulation. So with the proceeding polymerization and consequently also growing dough

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viscosity the temperature increases, as 57 kJ of polymerization heat are generated per mole MMA [11].

The specimen temperature was monitored by help of a FLIR thermo-vision camera, for about fifteen minutes after the cement preparation. The temperature monitoring started at 8:20 with 26.5^{0}C (fig.2), then figure 3 reveals the increase of temperature to 29^{0}C in the active area of the specimens, indicated by the cursor.

The temperature reaches high values, like 77.2^{0}C after 6 min from the cement preparation (fig.4), and then it starts diminishing slowly, reaching 28.4^{0}C after 15 min (fig.5). According to [8] the in vivo temperatures do not reach such high values, being around 44^{0}C-47^{0}C.

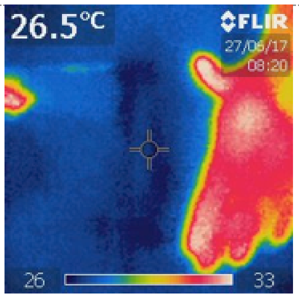

Fig. 2 Initial temperatures distribution

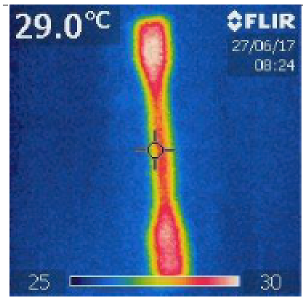

Fig.3 Temperatures distribution after 4 min

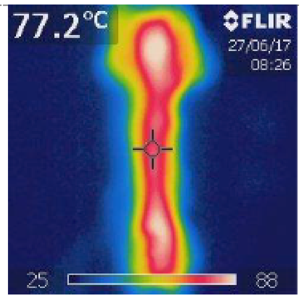

Fig.4 Temperatures distribution after 6 min

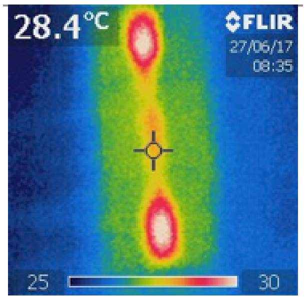

Fig.5 Temperatures distribution after 15 min

Monitoring the specimen's temperature is a method to determine the safe duration between the cement preparation and the insertion in the prosthetic joint, taking into account that the viscosity of the material is increasing in time and becomes more difficult to shape.

The tensile test is the next mandatory step, though some studies claim that specimens have similar characteristics during tensile and compression tests [10] but others show that cement is weak in tension and strong in compression, meaning that the tensile load should be carefully monitored in order to avoid joint loosening [11]. Such tests can only give a rough idea of the quality of a cement especially as their properties change under physiologic conditions (body temperature and fluids) and in so far the clinical relevance of test standards must be challenged [12].

To perform the tensile testing, the team used equipment from Lloyd Instruments capable of supporting application forces up to 50 kN and provide information both in text and excel files (fig.6) in order to obtain reliable information regarding the studied material, PMMA. One of the specimens is presented during the testing operation in figure 7.

All specimens were subjected to the tensile testing until they were destroyed, meaning until the breaking point of the material was reached. The values of the parameters during breaking were recorded for all the specimens.

Results and discussions

The Excel databases containing the tensile experiment results were used to produce diagrams which provide a

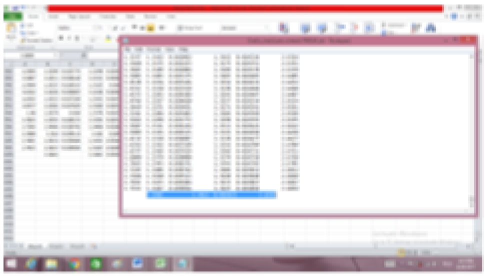
Fig.6 Test results


Fig.7 Specimen during tensile testing

more expressive way of presenting the information. The results obtained for specimen 2 are shown as an example in figure 8.

The graphical representation shows an obvious raise in the strain value proportional to the value of the load, along the entire elastic zone. The average breaking load was 1334.3N for an extension of 0.02mm and a maximum stress of 22.23MPa. As expected the material is not elastic, the breakage occurs sudden for relatively high values of the load, which are improbably to be reached during normal recovery exercises but the kinetotherapist should be aware of the stretching limits of the bone cement and avoid applying loads comparable to the body weight. Also, the duration of the exercises should be carefully monitored as the dynamical loads will put more stress upon the cement bonds than the static determinations showed in laboratory conditions.

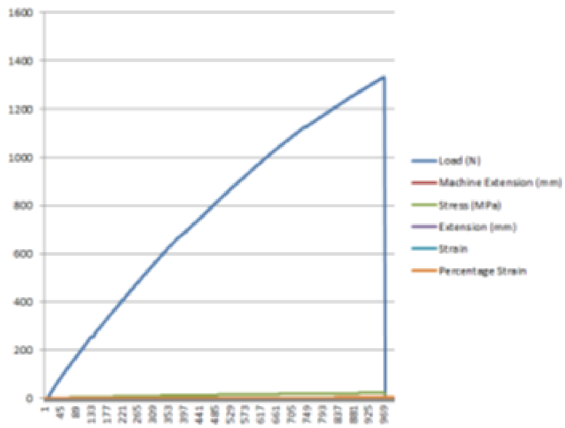

Fig.8 Graphical representation of the mechanical characteristics following the tensile testing

Conclusions

The paper addresses issues related to the use of PMMA in joint replacement that may occur during a less researched activity, like kinetotherapy after the surgery, meant to recover the patient's mobility. The stretching techniques should be applied in a careful manner, by avoiding the suspension of the entire body on the arms, tractions or lifting heavy weights (in case of shoulder surgery) and also the suspension using ankles (in case of hip or knee surgery).

As far as the exothermic polymerization reaction is concerned, the monitoring by help of a thermo-vision camera for several types of joint replacement surgeries may provide information for a large database regarding the safe duration between the cement preparation and the application on the prosthetic area, reducing the risk of BCIS.

Unfortunately, there still are risks related to the residual monomers that may enter the bloodstream, the duration between cement preparation and insertion is difficult to establish as the viscosity is increasing too much if the surgeon waits too long for the diminishing of exothermic reaction influence.

Further studies will be performed by interdisciplinary teams of engineers and doctors in order to address as many issues as possible and also preserving a lucrative connection between the technical and the medical area.

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