BULETINUL Universităţii Petrol – Gaze din Ploieşti	Vol. LXVII No. 1/2015	32 – 36	Seria Tehnică

Tensile Testing of Orthopedic Bone Cements

Lucian Bogdan*, Cristian-Sorin Neş*, Nicolae Faur*,
Jenel Marian Pătraşcu**

* Universitatea "Politehnica" din Timişoara, Bd. Mihai Viteazu, nr.1, Timişoara, Romania
e-mail: blucian85@gmail.com

** Universitatea de Medicină și Farmacie "Victor Babeş", Piața Eftimie Murgu, nr. 2, Timişoara

Abstract

This paper presents the results of tensile tests performed on Biomet® orthopedic bone cement currently used in arthroplasty. By direct molding of the cement, test specimens were manufactured with rectangular cross section shape and tested according to ISO 527. The stress–strain curves of all specimens tested exhibited similar linear elastic regime followed by brittle fracture.

The average ultimate tensile strength of the samples is 29.20 MPa, while the average modulus of elasticity was calculated at 3229 MPa. The obtained results can be used in order to asses the fatigue life-time of this type of bone cement.

Key words: *total hip replacement, bone cement, polymethylmethacrylate*

Introduction

The arthroplasty surgery consists in the reconstruction of a human joint. It is not applicable to every joint: in practice, its use is almost confined to the shoulder, the elbow, the hip, the knee and certain joints in the hand and foot.

Bone cement (polymethylmethacrylate - PMMA) has been used in cemented joint arthroplasty since the 1960s. The role of the cement is to fill the gap between the bone and the implants, thus connecting them together to achieve an optimal transfer of the loads generated during gait cycle and daily activities [1]. The long term success of the cemented joint depends on the stability of the bone-cement-implant interface. Although overall, this is a successful application, limitations have been identified.

These limitations are determined by mechanical factors like the loosening of the femoral component [2], fatigue and damage within the bone and cement at the bone/cement interface [3-4], interfacial porosity [5] and microcracks in the cement mantle [6]. Biological factors that influence the long term success of the implant are bone resorption and the reaction of the human body at the particles released by friction between the moving parts of the implant (e.g. femoral head-acetabular cup) [7-8].

Microcracks are the main factors that cause the failure of the cemented joint [9]. Their occurrence is influenced by fatigue wear of the cement mantle, geometry of the prosthesis stem, contact area and depth of the acrylic cement inside the bone, critical stress areas at prosthesis/bone cement interface as a result of articular moments and forces produced during the gait cycle and daily activities.

To asses the long term behavior of the bone-cement-implant interface, finite element analysis (FEA) is used. FEA models are based on accurate representations of geometric data (e.g. bone-cement-prosthesis geometry), material properties, boundary conditions and applied loads.

The literature provides mechanical properties for the stereotypical acrylic bone cement (modulus of elasticity, Poisson's ratio, etc); in reality, these properties depend on the chemical composition of the cement (saturated or unsaturated compounds, etc.).

This paper presents experimental tensile tests in order to determine the material properties of a specific bone cement currently used in orthopedic surgery. The obtained results can be used in FEA models of the hip joint arthroplasty.

Method

High viscosity bone cement, produced and supplied by Biomet® (*Biomet Orthopedics, Dietikon, Switzerland*) as polymer powder (44 g) and monomer liquid (18,8 g) portions was used. Table 1 present the chemical composition of this type of bone cement.

Table 1. The chemical contents of Biomet powder and liquid

Composition of bone cement powder	
Poly(methyl acrylate, methyl methacrylate) Zirconium dioxide Benzoyl peroxide	38.3 g 5.3 g 0.4 g
Composition of bone cement liquid	
Methylmethacrylate N,N-dimethyl-toluidine	18.4 g 0.4 g

Liquid and powder portions of the cement were chosen according to the manufacturer's instructions and were mixed at ambient temperature (23˚C). The mixed cement was inserted during the working time into a silicon mold with specified dimension according to ISO 527 (fig. 1).

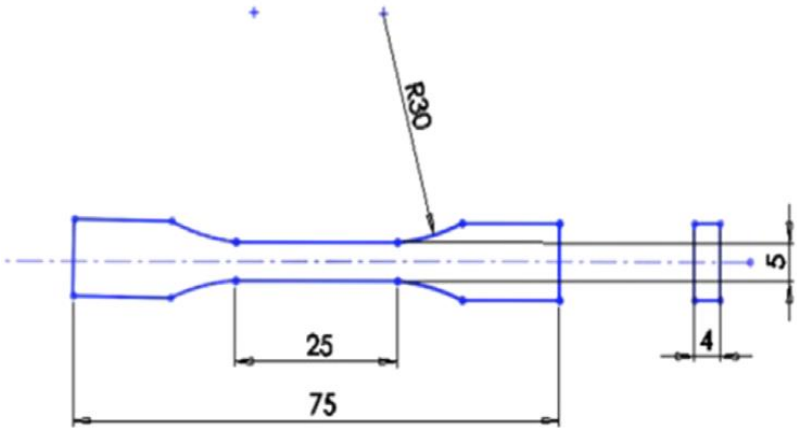

Fig. 1. Test specimen shape according to ISO 527

After 20-30 min the test samples where removed from the mold and kept for 24 h to ensure completion of the polymerization process. To obtain the final shape, all samples were polished with 600 grit abrasive paper in the longitudinal direction until the surface was free of mold marks. The specimens containing defects larger than 1 mm were excluded from the study.

The test specimens were soaked in PBS (phosphate buffered saline). It is recommended that specimens should continually be maintained in the PBS solution from a minimum of 7 days to 60 days according to ASTM F 2118-03.

The specimens were subjected to a tensile test on a hydraulic machine (Walter+Bai LFV-10kN - fig. 2) with a distance between grips of 35 mm. According to ISO 527, the testing speed was set at 1 mm/min. Special fixing devices were manufactured to ensure that the hydraulic grips don't produce critical stress areas to test specimens.

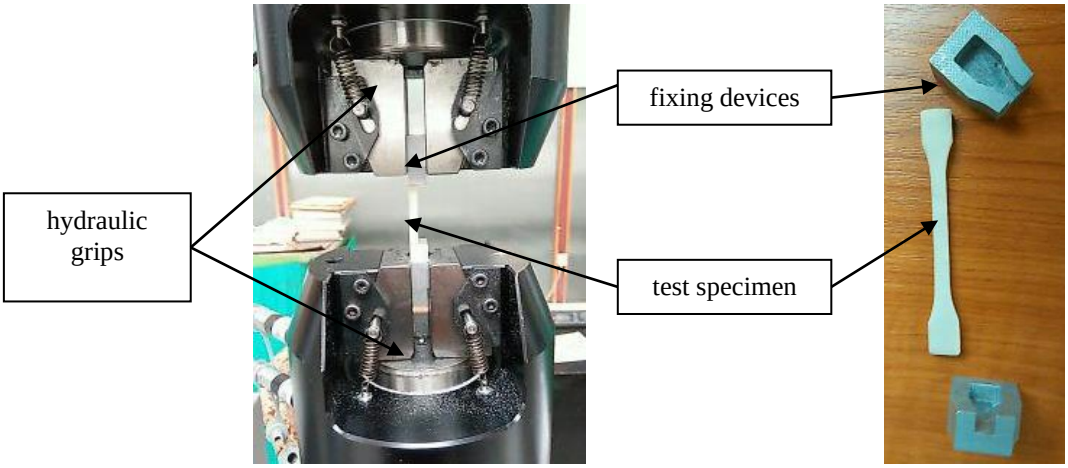

Fig. 2. Hydraulic machine model Baiag Walter LFV-10kN

Results and Conclusions

The tensile stress–strain curves of all bone cements specimens tested exhibited similar linear elastic regime followed by brittle fracture (Fig. 3). The flat interval that can be observed for specimens S4, S5 and S6 has been caused by the gaps between the specimens and the fixing devices. The calculation of the moduli of elasticity did not take into account these intervals.

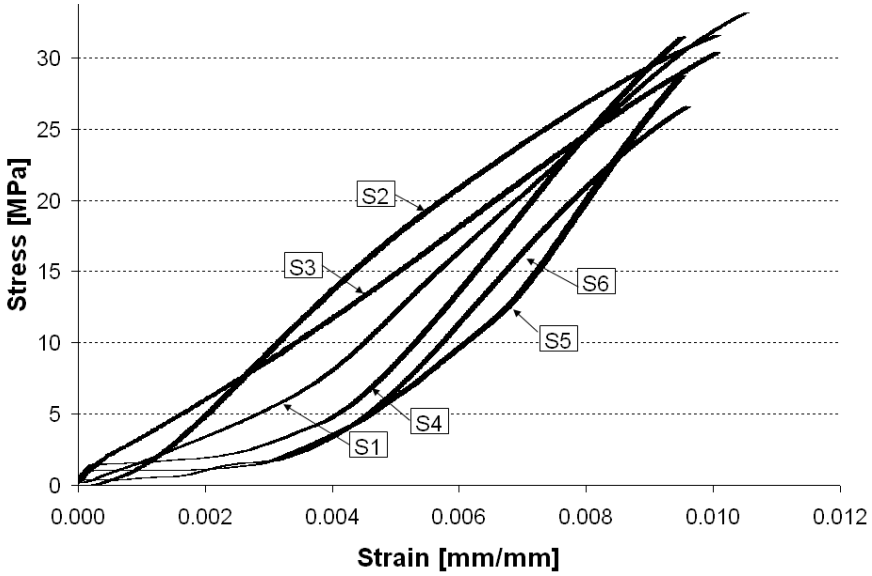

Fig. 3. Results obtained

Test results show that the average ultimate tensile strength of the samples is 29.20 MPa (range: 25.30 – 33.16 MPa). The average specific strain (1) of the samples is 0.992% (range: 0.956% – 1.055%). Using equation (2), the longitudinal modulus of elasticity was calculated for each sample. The average modulus for all the bone cement samples tested was determined to be 3229 MPa (range: 2908.5 - 3471.5 MPa). The results are in agreement with the data from the literature: the acrylic bone cement exhibits linear-elastic behaviour, thus in FEA it can be modelled only using the modulus of elasticity and Poisson's ratio. On the other hand, the value of the modulus of elasticity is 20% larger than the value obtained by Kurtz et al. [10].

$$\varepsilon = \frac{l - l_0}{l_0} \tag{1}$$

$$E = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1} \tag{2}$$

This shows that cements of the same type (acrylic), but with slightly different chemical composition behave significantly different.

Acknowledgment

This work was partially supported by the strategic grant POSDRU/159/1.5/S/137070 (2014) of the Ministry of National Education, Romania, co-financed by the European Social Fund – Investing in People, within the Sectoral Operational Programme Human Resources Development 2007-2013.

References

1. Sheafi, E.M., Tanner, K.E. – Effects of test sample shape and surface production method on the fatigue behavior of PMMA bone cement, *Journal of The Mechanical Behavior of Biomedical Materials*, Vol. 29, 2014, pp. 91-102.
2. Yang, D.T. et al. – Fatigue of the bone/cement interface and loosening of total joint replacements, *International Journal of Fatigue*, Vol. 32, 2010, pp. 1639-1949.
3. Mohler, C.G. et al. – Early loosening of the femoral component at the cement-prosthesis interface after total hip replacement, *Journal of Bone Joint Surgery*, Vol. 77A, , 1995, pp. 1315-1322.
4. Kim, D.G. et al. – A fatigue damage model for the cement-bone interface, *Journal of Biomechanics*, Vol. 37, 2004, pp. 1505-1512.
5. Pelletier, M.H. et al. – Pore distribution and material properties of bone cement cured at different temperatures, *Acta Biomaterialia*, Vol. 6, 2010, pp. 886-891.
6. Mann, K.A. et al. – Stem-cement porosity may explain early loosening of cemented femoral hip components: experimental-computational in vitro study, *Journal of Orthopedic Research*, Vol. 25, 2007, pp. 340-350.
7. Vorndran, E. et. al. – Ready-to-use injectable calcium phosphate bone cement paste as drug carrier, *Acta Biomaterialia*, Vol. 9, 2013, pp. 9558-9567.
8. Matos, A.C. et. al. – A novel modified acrylic bone cement matrix. A step forward on antibiotic delivery against multiresistant bacteria responsible for prosthetic joint infections, *Materials Science and Engineering C*, Vol. 38, 2014, pp. 218-226.
9. Zhang, L.F. et al. – A Bond strength analysis of the bone cement-stem interfaced of hip arthroplasties. *Asian Pacific Journal of Tropical Medicine*, 2014, pp. 153-159.
10. Kurtz, S.M. et al. – Static and fatigue mechanical behavior of bone cement with elevated barium sulfate content for treatment of vertebral compression fractures. *Biomaterials*, Vol. 26, 2005, pp. 3699-3712.

Încercări experimentale de tracţiune asupra cimenturilor acrilice osoase

Rezumat

În această lucrare sunt prezentate teste experimentale de tracţiune asupra cimenturilor osoase marca Biomet® folosite în prezent la operaţiile de artroplastie. Prin turnare, în matriţe de silicon, au fost realizate epruvete cu secţiune rectangulară conform standardului ISO 527.

Din rezultatele obţinute în urma testelor experimentale de tracţiune se observă o comportare liniar elastică urmată de rupere fragilă. Valoarea medie obţinută a rezistenţei de rupere la tracţiune este de 29.20 MPa, iar valoarea medie calculată a modulului de elasticitate este de 3229 MPa