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Low-cycle fatigue of surgical cements

A. Balin*, G. Junak
Department of Materials Mechanics, Silesian University of Technology,
ul. Krasińskiego 8, 40-019 Katowice, Poland
* Corresponding author: E-mail address: alicja.balin@polsl.pl

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Properties

ABSTRACT

Purpose: In case when surgical cement is used to fix endoprostheses of joints the fatigue character of mechanical interraction in the cement seems to be a significant importance. The paper suggests to adapt the research method of low cycle fatigue for modelling the loads on surgical cements in an artificial hip joint. Surgical cements have also been modified in order to improve their functional properties.
Design/methodology/approach: Low cycle fatigue tests were conducted on samples made from Palamed cement without an addition and on samples modified with glassy carbon and titanium. The tests were conducted on a servohydraulic fatigue testing machine, MTS-810, with displacement control.
Findings: Fatigue tests proved viscoelastic character of all the tested materials. During the fatigue tests, the phenomenon of stress cyclic relaxation was observed.
Research limitations/implications: Modelling the loadings of cement in endoprostheses of joints with the low cycle fatigue method takes into account all high value stresses, while cement is being used for endoprostheses for many years in the conditions of random stress and deformation courses. Therefore the obtained stress and deformation values are bigger than those which would have been obtained in real conditions in the same time.
Practical implications: The low cycle fatigue tests carried out showed how important is the factor of time for the behavior of surgical cement in the conditions of changeable loadings. This fact is essential to assess its usability for endoprosthesoplasty of joints, specially of a hip joint. Post deformation return which is a characteristic feature for material viscoelasticity enables its regeneration conditioning expected durability of endoprosthesis of joints.
Originality/value: Low cycle fatigue testing method for modelling of loads on surgical cement in artificial hip joint enables to carry out the tests in a shorter period of time.
Keywords: Fatigue; Biomaterials; Mechanical properties; Modelling

1. Introduction

In spite of a number of constructional solutions of endoprostheses, endoprosthesoplasty with the use of cement is still one of the basic procedures in surgical treatment of joints [1,2]. The most often implanted joint is the hip joint, being under the greatest load in the human organism.
Durability of the artificial hip joint, especially in the case of cement anchoring of endoprosthesis components, depends to a large extent on rheological processes, in particular creep and relaxation. Surgical cement, being a polymer composition, in a model approach represents a classical example of a viscoelastic substance [3-11]. A bone can be also treated as a viscoelastic material. [12,13].
In connection with the rheological properties of the bonds made of materials which anchor the endoprosthesis in the femoral bone channel, the problem of evaluation of the artificial hip joint's durability is complex.

From among many properties of surgical cement, which influence the durability of cement endoprosthesoplasty, the most important for a clinical verification are those which directly depend on the action of cyclic loads, both in a short- and a long-term period [14]. In a 24-hour period, there are periods of both physical activeness and periods of rest in a typical patient. They are connected with variable characteristics of load imposed on the joint and the cement inside it, the latter being one of the joint's components [15-17]. The phenomenon of cement degradation during the person's movement takes place under the action of cyclic changes of loads of high values. Therefore, they can be defined with high probability as fatigue in the range of a small number of cycles. Bearing this in mind, the authors have made an evaluation in this paper of cement behaviour in an artificial hip joint, applying the low-cycle fatigue testing method.

2. Materials and method

Fatigue tests were conducted on samples made from cement of the manufacturer's name Palamed 40 without an addition and on samples modified with glassy carbon and titanium. By adding glassy carbon in the form of powder of 10-160 μm granulation and titanium particles of 25-150 μm size and 3.2% mass fraction, an attempt was made to modify the applied PMMA-based (methyl polymethacrylate) cements for the purpose of decreasing their high curing temperature and shrinkage in the polymerization process. Creation of the polymer-ceramic compositions is the future direction of the polymer application [18,19]. Carbon, as a material compatible with a living organism, has found an application in medicine [20,21]. The titanium alloys are applied as a load bearing implant in orthopedic surgery [22,23].

The strength properties: ultimate compressive strength R_c and ultimate bending strength R_g as well as Young's modulus elasticity E of the composites obtained do not significantly differ when compared to the respective properties of cement without such addition (Fig. 1 and 2).

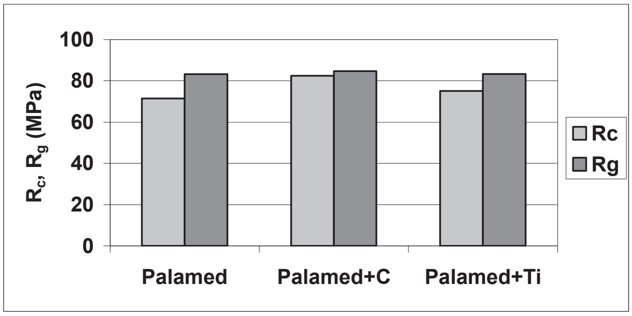

Fig. 1. Strength properties of Palamed 40 cement modified with glassy carbon (C) and titanium (Ti)

The tests were conducted on a servohydraulic fatigue testing machine, MTS-810, with displacement control. The machine is equipped with a digital control system, TestSTAR II. In order to ensure precise collection of all values of force, stroke and deformation, the tests were carried out using the TestWARE SX programme. A change of displacement was modelled with a triangular cycle of 0.25 Hz frequency. The characterization of the cycle is presented in Fig. 3 and of the tests' algorithm, in Fig. 4.

For the tests, a method of cyclic loading of the samples was assumed which induces variable stresses in the area of tensile stresses. The action of tensile stresses is particularly adverse to cement in a proximal area of the bone-prosthesis system [16,24], since it may lead to cement cracking [12,16,25-29]. The method of cyclic load assumed for the tests was one where variable stresses are induced in the area of tensile stresses from zero to the maximum value of ca. 17 MPa. The values of the stresses are similar to those of tensile stress, obtained in the model investigations presented in the literature [30,31] and, at the same time, ca. 2 times lower than the tensile strength R_m of surgical cement [31]. Thus, the most strict research conditions were assumed for the cement. According to the literature [4], it is recommended for viscoelastic materials to induce load in the form a predefined strain (kinematic load). With this in mind, in the low-cycle fatigue tests carried out within this study, a method was established of loading surgical cement samples, consisting in displacement control. It was assumed that maintaining a constant value of the displacement range Δv will have an indirect influence on maintaining a constant value of the deformation range, whilst the force will be changing as the number of cycle grows. Such method of carrying out the fatigue tests enables the modelling of the cyclic relaxation phenomenon, characteristic of polymer composites which include the investigated surgical cement.

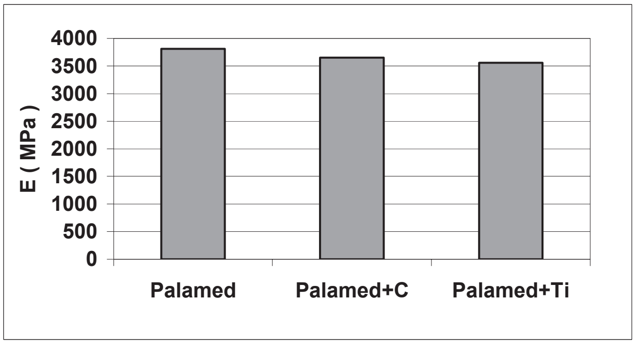

Fig. 2. Young's modulus elasticity for Palamed 40 cement modified with glassy carbon (C) and titanium (Ti)

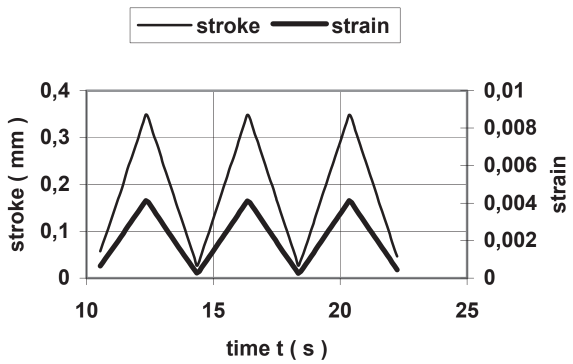

Fig. 3. Triangle shaped cycle of displacements and straines in fatigue tests

During the tests, diagrams were recorded of load F dependence on displacement v of the servo-motor with an increase of the number of cycles, N. For all samples of cement without an addition as well as those modified with glassy carbon and titanium, the recorded dependencies of load change F on displacement v in the cycle had the nature of a hysteresis loop (Fig. 5). The nature of the dependencies obtained can be accounted for by the viscoelastic behaviour of the material.

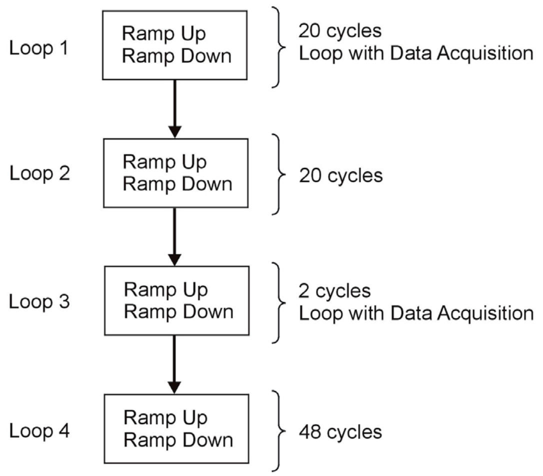

Fig. 4. Algorithm of the low cycle fatigue test

During the fatigue tests, the phenomenon of stress relaxation was observed, manifested by a periodical reduction of force ΔF with the growing number of cycles N, when a constant displacement amplitude Δv was maintained. Where intervals were applied during the application of load, the so-called elastic recovery occurred. After repeated load imposed on a sample after a break of several hours and determining the predefined constant value of the *Δv* displacement range, the maximum force in the cycle assumed the same value as at the beginning of the test.

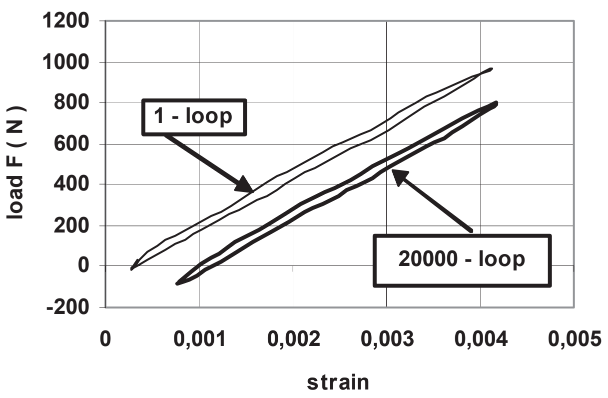

Fig. 5. Exemplary hysteresis loops with increased cycle number recorded in the course of low cycle fatigue investigations of Palamed 40 cement samples

The above phenomenon can be accounted for by viscoelasticity which, being the property of polymers, is not an ordinary sum of Hook's elastic properties and Newton's viscous properties. It contains another, third component, namely the non-elasticity phenomenon. It consists in reversible strain having two components: one "instantaneous", proceeding in time shorter than the time of the experiment and the other one, "delayed", which requires several minutes, hours, or even longer time to recover the initial state [3,4].

This is of considerable significance for biofunctionality of an artificial joint, since elastic recovery, being a property of material's viscoelasticity, enables, where intervals are applied in load imposing, "regeneration" of cement in the human organism, which conditions the sufficient durability of the artificial joint.

The results of durability N_f varied for the investigated samples. The samples cracked at random due to the presence of pores in the cement as well as fillers which do not undergo polymerization.

3. Conclusions

Approximation of the results obtained under the study for the total cement lifetime in the human organism is difficult. Surgical cement operates in an artificial hip joint for many years in the conditions of random courses of stresses and strains. Modelling of loads imposed on cement in an artificial hip joint, when using the low-cycle fatigue testing method, takes into account only the action of stresses of the highest values. Therefore, the criteria of durability, boundary values of strain or stresses, are more strict than those that could be applied for real objects. Besides, the manner of using an artificial joint and the resultant load imposed on it, including cement as one of its components, is an individual quality of the patient, his/her physical activity and physiological factors.

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