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EXPERIMENTAL MEASUREMENT OF MECHANICAL PROPERTIES OF THE BONE CEMENT

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Abstract:
The contribution deals with en experimental measurement of mechanical properties of the bone cement. Where bone cements (PALACOS R and SMARTSET HV) were mixed by two techniques (manual mixing and manual mixing in vacuum) and they were measured under different conditions (temperature, moisture). Measured data were evaluated by statistical analysis. Retrieved results were used for finite element material model of bone cement which is part of hip replacement study by finite element method.

1. Introduction

Implantation of hip joint endoprosthesis is related with method of it's fixation in bone tissue. One way of fixation is special surface layer, which allows growing bone tissue into surface. Another way is fixing implant by bone cement, where bone cement is creating junction between bone tissue and implant. Mechanical behaviour of this junction has a significant influence for reliability of hip joint because one of the main reasons of implant failure is release the implant from bone tissue. In this article we are investigating basic mechanical properties characterising mechanical behaviour of bone cement for two reasons: 1) for comparative analysis of different types and different measuring conditions of bone cement, 2) to determining input values for material model and then for computer modelling which can predict (with some presumption) behaviour of implant in human body. Today is computer modelling important part of scientific work or part of solving programs in industry. To create computer model we have to create partial models which one of them is material model of bone cement. And this material model needs necessary input data for its description. Necessary input data in our material model means to choose distinguishing level which is deciding what material model we have to pick. Simplest material model is described by material which is linear, isotropic and homogenous.

Problem was formulated subsequently: Determination of mechanical properties of bone cement. For material model description we used two characteristic: Young's modulus and flexural strength. The problem was solved by experimental modeling.

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2. Materials and methods

For our investigation we have two types of high viscosity [3] bone cement: PALACOS R and SMARTSET HV. Each package of cement included two components: monomer (liquid consistence, Figure 1) and polymer (powder consistence). Preparation of cement was proceed by manual mixing of components in open cup and vacuum mixing of components by special tool supplied by manufacturer (Figure 3, Figure 4). For making specimens we have to use special form (Figure 2). After properly mixing bone cement was cabined into first part of form. And after screw together with second part of form, bone cement filled form cavity uniformly. We have to apply bone cement into form cavity quickly because high viscosity bone cement becomes hard very soon.

Figure 1*: Monomer of bone cement.*

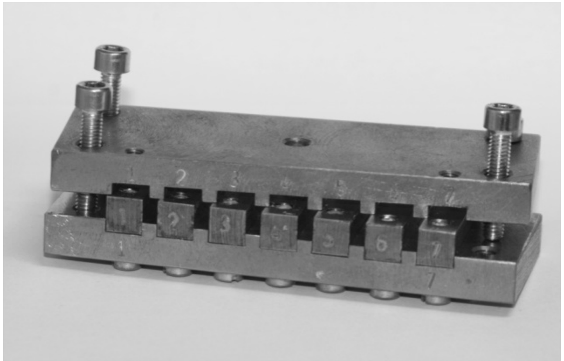

Figure 2*: Form for make-up specimens of bone cement.*

After finished bone cement polymerization and hardened we take apart form and removed specimens, which were rubbing lightly by sand paper. Specimens have rectangle cross section (3x4x45 mm).

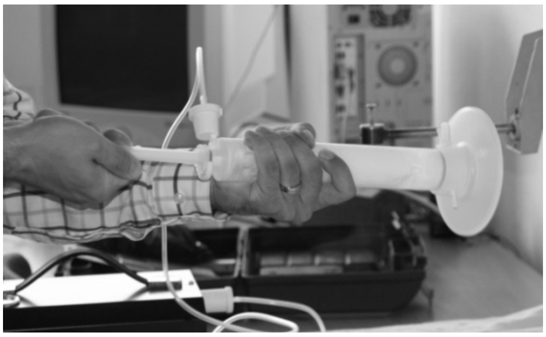

***Figure 3:** Vacuum mixing in laboratory.*

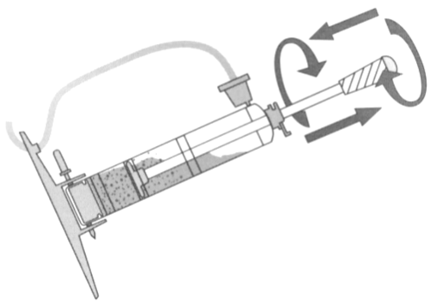

***Figure 4:** Illustration of vacuum mixing from instruction leaflet.*

Our institute of Solid Mechanics, Mechatronics and Biomechanics own one of the computer controlled testing station ZWICK Z 020 – TND for tests in tension and compression zone. Additionally we used with this testing station the position sensor with sensitivity 0.1 micrometer and load cell with range 100 N.

In this paper our work was aimed to testing equality of mean values of Young's modulus for each variant of specimens which is summarized by Table 1. We divide specimens into following classes (except already mentioned types of mixing and types of cements):

- Measurement under temperature 37°C (rests of specimens were measured over temperature 22°C)

- Measurement under “moisture”, which simulate human body surroundings (specimens were practically wetted in solution physiological before measurement). Number of PALACOS R specimens were limiting therefore there was created only one variant.

Table 1: *Variants of specimens of bone cement.*

Type of specimens	**Manual mixing**	**Manual mixing in vacuum**	**Manual mixing in vacuum, moisture**	**Manual mixing in vacuum, temperature 37°C**	**Manual mixing, temperature 37°C**
SMARTSET HV	12 specimens	20 specimens	7 specimens	12 specimens	14 specimens
PALACOS R	12 specimens	x	x	x	x

3. Results

3.1. Testing of equality of mean values of Young’s modulus

Loading specimens were proceeding on four-point bending tool which shows Figure 5 and Figure 6 [1]. The output of our measurement was dependence on loading force to deflection of specimens shown in Figure 7. With this dependence we could estimate Young’s modulus and with presumption of crack of the specimen we could estimate flexure strength [2]. Measurement of flexure strength was quite difficult because the four-point tool cannot allow crack of the specimen. Therefore there were tried out three-point tool. We could note some improvement but still three-point tool cannot work in a lot of specimens.

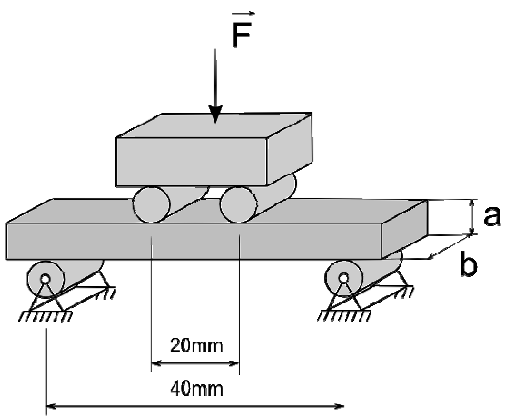

Figure 5: *Scheme of four-bend test.*

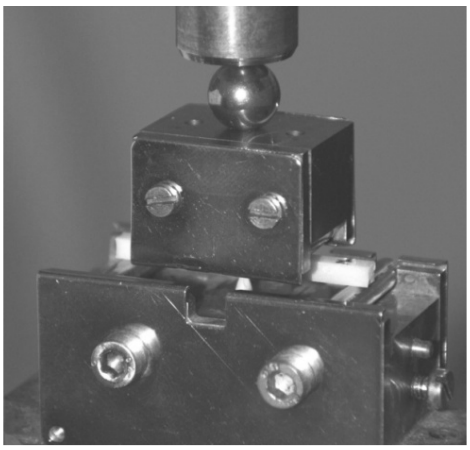

Figure 6: *Realization of four-bend test.*

For following testing of equality of mean values of Young’s modulus and flexure strength from each data class by statistical method it was necessary to verify if we could suppose normal data distribution and verify equality of variances. It was checked by Anderson-Darling test on significance level $\alpha = 0.05$, so that we could suppose normal distribution of all data. And equality of variances was checked by Bartlets test, where we could not reject the null hypotheses that variances from all data class were the same.

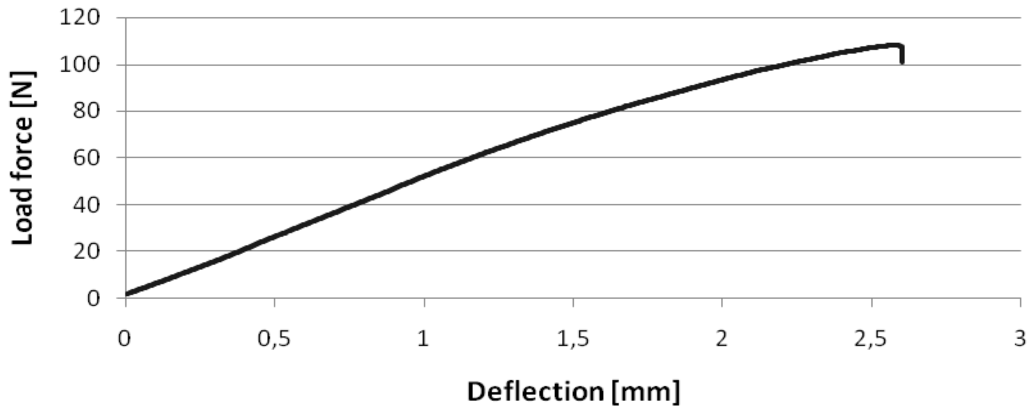

Figure 7: *Dependence on loading force to deflection with measurement by four-point bend.*

Following tables are showing results from Two-sample T test (expressed by p-value) which testing null hypothesis of equality of the mean values of Young's modulus at the significant level $\alpha = 0.05$. Where the result of test and basic statistic are shown in tables (from Table 2 to Table 7) where each value was estimated with 0.95 confidences. All of statistic testing was made down in statistical software Minitab 15.

Table 2**:** *Type of specimen and their mean and interval estimation plus p-value of two-sample T test.*

Type of specimen	**Sample mean (interval estimation) [GPa]**	**Standard deviation [GPa]**	**p-value**
PALACOS R manual mixing	3.410 (3.344; 3.476)	0.104	0.017
SMARTSET HV manual mixing	3.527 (3.453; 3.601)	0.116	

Table 3**:** *Type of specimen and their mean and interval estimation plus p-value of two-sample T test.*

Type of specimen	**Sample mean (interval estimation) [GPa]**	**Standard deviation [GPa]**	**p-value**
SMARTSET HV manual mixing in vacuum	3.440 (3.363; 3.517)	0.165	0.121
SMARTSET HV manual mixing	3.527 (3.453; 3.601)	0.116	

Table 4**:** *Type of specimen and their mean and interval estimation plus p-value of two-sample T test.*

Type of specimen	**Sample mean (interval estimation) [GPa]**	**Standard deviation [GPa]**	**p-value**
SMARTSET HV manual mixing in vacuum	3.440 (3.363; 3.517)	0.165	0.004
SMARTSET HV manual mixing, moisture	3.207 (3.048; 3.366)	0.172	

Table 5: *Type of specimen and their mean and interval estimation plus p-value of two-sample T test.*

Type of specimen	Sample mean (interval estimation) [GPa]	Standard deviation [GPa]	p-value
SMARTSET HV manual mixing, temperature 37°C	2.674 (2.569; 2.778)	0.181	0.001
SMARTSET HV manual mixing in vacuum, temperature 37°C	2.948 (2.816; 3.080)	0.208	

Table 6: *Type of specimen and their mean and interval estimation plus p-value of two-sample T test.*

Type of specimen	Sample mean (interval estimation) [GPa]	Standard deviation [GPa]	p-value
SMARTSET HV manual mixing	3.527 (3.453; 3.601)	0.116	< 0.0005
SMARTSET HV manual mixing, temperature 37°C	2.674 (2.569; 2.778)	0.181	

Table 7: *Type of specimen and their mean and interval estimation plus p-value of two-sample T test.*

Type of specimen	Sample mean (interval estimation) [GPa]	Standard deviation [GPa]	p-value
SMARTSET HV manual mixing in vacuum	3.440 (3.363; 3.517)	0.165	< 0.0005
SMARTSET HV manual mixing in vacuum, temperature 37°C	2.948 (2.816; 3.080)	0.208	

3.2. Testing of equality of mean values of flexural strength

From dependence on loading force to deflection (**Figure 7**) we can estimate except Young’s modulus additionally flexural strength in case that the loading force cause specimens crack. Following **Table 8** showing mean of flexural strength from two variants:

Table 8: *Evaluation of flexural strength of two data class with p-value and basic statistic.*

Type of specimen	Sample mean (interval estimation) [GPa]	Type of measurement	p-value
SMARTSET HV manual mixing	74.7 (66.55; 82.75)	Four-point bend	0.023
SMARTSET HV manual mixing in vacuum	86.4 (78.10; 94.72)	Three-point bend	

4. Conclusion

From statistical outcome of measured Young's modulus data we can describe following points of conclusion:

- At the level of significance $\alpha = 0.05$, we are rejecting the null hypothesis about equality of mean value and accepting alternative hypothesis in tested variants:

  Cement type, way of preparing, temperature and moisture has significant influence to Young's modulus. Test was proved that:

  - Bone cement SMARTSET HV prepared by manual mixing has significant higher values of Young's modulus than bone cement PALACOS R prepared by manual mixing (**Table 2**). So that SMARTSET HV has (in linear part of dependence on loading force to deflection) a higher stiffness than PALACOS R.

  - Bone cement SMARTSET HV prepared by manual mixing in vacuum has significant higher values of Young's modulus than bone cement SMARTSET HV prepared by manual mixing in vacuum measured under moisture (**Table 3**). In this case can be significant higher mean of Young's modulus caused by small data class of SMARTSET HV manual mixing in vacuum under moisture bone cement.

  - Bone cement SMARTSET HV prepared by manual mixing in vacuum measured under temperature 37°C has significant higher values of Young's modulus than bone cement SMARTSET HV prepared by manual mixing measured under temperature 37°C (**Table 4**).

  - Bone cement SMARTSET HV prepared by manual mixing has significant higher values of Young's modulus than bone cement SMARTSET HV prepared by manual mixing measured under temperature 37°C (**Table 5**).

  - Bone cement SMARTSET HV prepared by manual mixing in vacuum has significant higher values of Young's modulus than bone cement SMARTSET HV prepared by manual mixing in vacuum measured under temperature 37°C (**Table 6**).

- At the level of significance $\alpha = 0.05$, we are not rejecting the null hypothesis about equality of mean value and accepting alternative hypothesis in tested variant:

  - Statistical test was proved (**Table 7**) that the way of cement preparing (manual mixing and manual mixing in vacuum) in bone cement type SMARTSET HV has not significant higher values of Young's modulus measured under normal temperature (22°C).

From statistical outcome of measured flexural strength data (**Table 8**) we can describe following points of conclusion:

- At the level of significance $\alpha = 0.05$, we are rejecting the null hypothesis about equality of mean value of flexure strength and we are accepting alternative hypothesis.

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