Compression and Bending Tests in order to Evaluate the Use of Necuron for the Manufacturing of Transtibial Prostheses

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Polyurethanes are used in many areas of bioengineering as they are biocompatible and present various mechanical properties according to the needs of each application. Necuron is a polyurethane that has been valued in many areas of industry. This paper presents compressive and three point bending testing done on three types of Necuron (840, 1020, 1300) with the purpose of evaluating its mechanical properties in order to use Necuron as a new material for transtibial prostheses. Results have shown Necuron 1300 to be a good candidate to fulfill this goal. Still there is need of further experimental programs to obtain reliable statistical information regarding the mechanical properties of Necuron.

Keywords: Necuron, compression, bending, transtibial prostheses.

Polyurethanes (PURs) are extensively known for their vastly differing mechanical and biological properties. Due to their good biocompatibility they are receiving increasing interest for the use in the medical field. They are appropriate materials for the development of many medical devices because of superior properties like biostability, good machining, high stiffness, wear resistance low absorption of humidity [1, 14, 16]. Due to these unique properties they are used in manufacturing of various blood bags, many extracorporeal or implantable medical devices such as various vascular catheters, the total artificial heart, small caliber vascular grafts for vascular access and arterial reconstruction or bypass, pacemaker leads, tissue replacement and augmentation and sewing rings for heart valves as well as heart valve prostheses [2, 15].

Polyurethanes are also very useful for high-load-bearing applications such as bone scaffolds due to properties such as durability, elastic character, and resistance to fatigue [2-6].

Taking the above into account the aim of this research was to determine the use of Necuron 840, 1020 and 1300 as a bioengineering material in the manufacturing of transtibial prostheses.

Transtibial prostheses like SACH®, Monolimb®, SATHI® or Niagara Foot®, need to be light, have a high wear resistance and a proper elasticity but also to have a low cost regarding materials and manufacturing [7-11]. These are properties that Necuron can accomplish and as Necuron has many types available this research tested three that were thought to be most suitable for the purpose in mind.

A secondary goal of this research was to better characterize Necuron as there is still need to gather knowledge regarding the mechanical characteristics of these materials, especially due to the fact that many data sheets of manufacturers lack reliable information regarding material properties and they usually differ from one producer to another [12, 13].

Compression and bending tests were chosen being the more representative type of loads on biomechanical orthopedic structures like transtibial prostheses. Also, this kind of structures are often designed, from functionality reasons, with holes and other types of stress concentration and thus the understanding of the response of materials with defects became extremely important.

Experimental part

Materials and testing methodology

All tests were carried out on an INSTRON MTS 810, 300 kN testing machine. The PUR materials used in this research were made by NECUMER GmbH.

<u>Compression tests</u>

The tests were performed according to ASTM D695-10 on specimens with the shape from figure 1 and dimensions according to table 1.

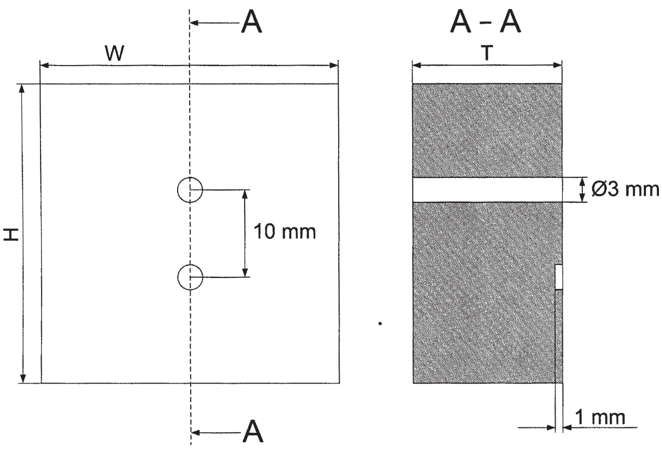

Fig. 1. Specimens for compressive testing (W-width, H-height, T-thickness)

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No.	Type of Necuron	Width [mm]	Thickness [mm]	Height [mm]	Defects
1	840	27.90	13.60	30.00	-
2		27.81	13.59	30.00	-
3		27.86	13.56	30.00	-
4		27.87	13.74	30.02	D
5		26.50	13.74	29.99	D
6		27.85	13.65	29.98	D
7	1020	26.53	13.63	30.07	-
8		26.48	13.57	30.08	-
9		26.58	13.69	30.05	-
10		26.55	13.58	30.07	-
11		27.81	13.60	30.04	-
12		27.80	13.70	30.08	-
13		27.85	13.43	30.07	D
14		27.82	13.63	30.08	D
15		27.81	13.56	30.04	D
16		29.70	13.41	29.69	D
17		29.74	13.27	29.69	D
18		29.65	13.33	29.69	D
19	1300	26.51	13.62	30.01	-
20		26.53	13.63	30.00	D
21		27.83	13.60	30.02	D

Table 1
DIMENSIONS OF SPECIMENS FOR EACH TYPE OF NECURON USED FOR COMPRESSION TESTING

Loading speed was 1 mm/min and tests were performed at room temperature (T=23°C).

In order to study the influence of defects, for each material type, part of the specimens were left flawless and part were realized with a defect, D in table 1, consisting of one through hole of 3 mm diameter and one partial hole of 3 mm diameter and 1 mm depth, placed axial at 10 mm distance (fig. 1).

Using the recorded data (load and deformation), the stress–strain curves were obtained (figs. 3–5) and the mechanical characteristics, modulus of elasticity in compression, compressive strength and compressive yield strength were determined.

Bending tests

The three point bending tests were performed according to SR EN ISO 178 on specimens with the shape from figure 2 and dimensions according to table 2.

Loading speed was 1 mm/min and tests were performed at room temperature (T=23°C).

Again part of the specimens were left flawless and part were realized with a defect, D in table 2, consisting of one through hole of 3 mm diameter and one partial hole of 3 mm diameter and 1 mm depth, placed axial at 10 mm distance (fig. 2). Distance between grips was 81 mm.

Using the recorded data (load and deformation) during the tests, the stress–strain curves were obtained (figs. 6–8)

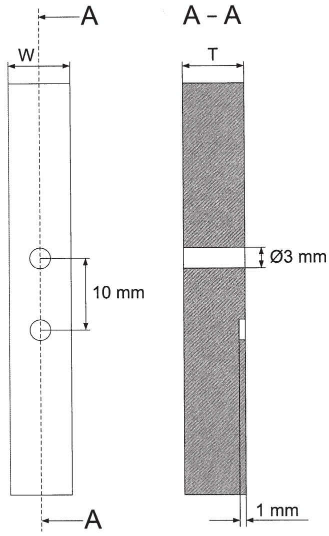

Fig. 2. Specimens for bending tests (W–width, T–thickness)

and the mechanical characteristics, flexural modulus of elasticity, flexural strength and maximum flexural strain were determined.

Results and discussions

The obtained values along with the standard deviation of the determined mechanical parameters for the different

No.	Type of Necuron	Width [mm]	Thickness [mm]	Defect
1	840	13.56	13.27	-
2		13.57	13.25	-
3		13.62	13.25	D
4		13.66	13.26	D
5	1020	13.33	14.58	-
6		13.50	14.51	-
7		13.49	14.43	-
8		13.48	14.61	-
9		13.48	14.47	-
10		13.49	14.60	D
11		13.46	14.60	D
12		13.51	14.58	D
13		13.49	14.61	D
14		13.43	14.50	D
15		13.47	14.44	D
16	1300	13.40	13.26	-
17		13.63	13.25	-
18		13.42	13.28	D
19		13.62	13.28	D

Table 2
DIMENSIONS OF SPECIMENS FOR EACH TYPE OF NECURON USED FOR BENDING TESTS

Table 3
VALUES AND STANDARD DEVIATION OF MECHANICAL PROPERTIES FOR THREE TYPES OF NECURON

Type of material	Mechanical property	No defect	With defect
Necuron 840	Modulus of elasticity in compression [MPa]	1622.23 ±121.40	1551.03 ±60.91
	Compressive strength [MPa]	66.72 ±15.15	72.99 ±15.38
	Compressive yield strength [MPa]	-	-
	Flexural modulus of elasticity [MPa]	1554.41 ±47.92	1335.10 ±29.44
	Flexural strength [MPa]	46.90 ±1.01	36.64 ±0.34
	Maximum flexural strain [%]	3.88 ±0.09	3.31 ±0.07
Necuron 1020	Modulus of elasticity in compression [MPa]	2103.81 ±47.56	2093.21 ±31.07
	Compressive strength [MPa]	95.31 ±24.48	81.16 ±2.86
	Compressive yield strength [MPa]	65.67 ±1.21	65.73 ±2.57
	Flexural modulus of elasticity [MPa]	2711.56 ±48.47	2684.89 ±60.49
	Flexural strength [MPa]	81.63 ±1.46	83.06 ±3.13
	Maximum flexural strain [%]	5.15 ±0.18	5.82 ±0.11
Necuron 1300	Modulus of elasticity in compression [MPa]	1938.01	1861.65 ±16.94
	Compressive strength [MPa]	111.93	75.64 ±4.47
	Compressive yield strength [MPa]	70.75	65.93 ±0.05
	Flexural modulus of elasticity [MPa]	1935.78 ±71.54	1818.08 ±36.09
	Flexural strength [MPa]	77.11 ±4.38	74.40 ±4.03
	Maximum flexural strain [%]	15.44 ±3.06	24.74 ±7.99

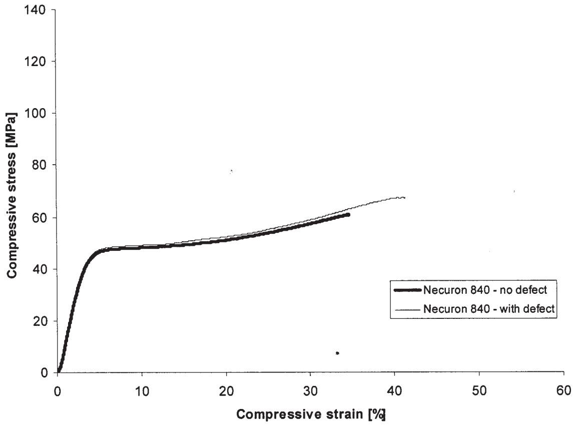

Fig. 3. Stress–strain curve of Necuron 840 with and without defects

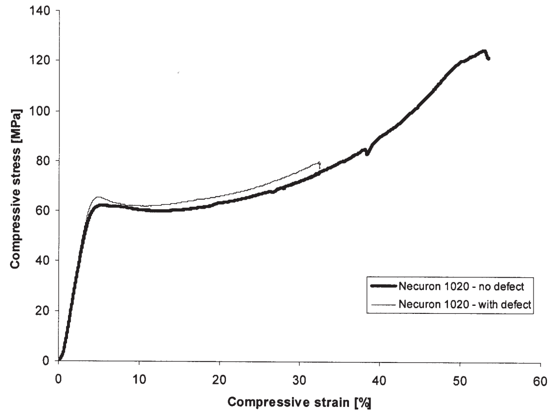

Fig. 4. Stress–strain curve of Necuron 1020 with and without defects

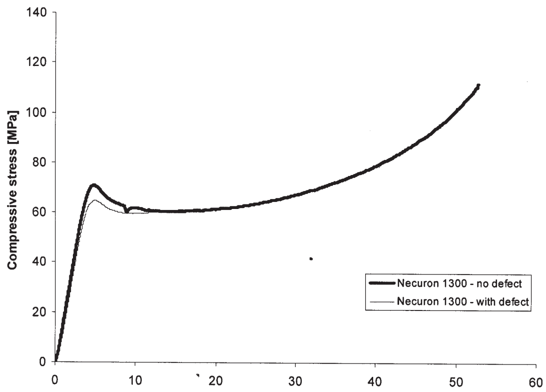

Fig. 5. Stress–strain curve of Necuron 1300 with and without defects

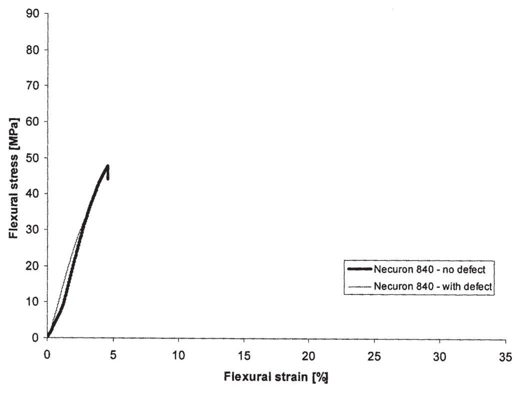

Fig. 6. Stress–strain curve of Necuron 840 with and without defects

types of Necuron, with and without flaws, are presented in table 3.

Figures 3 to 5 show the stress–strain curves obtained after compression for the three Necuron types showing the normal curve and a curve for the induced defects.

Figures 6 to 8 show the stress–strain curves obtained after bending for the three Necuron types showing the normal curve and a curve for the induced defects.

From table 3 it can be seen that out of the three types of Necuron tested the most suitable to be used as a material for transtibial prostheses is Necuron 1300 as it exhibits high compressive and flexural strength and optimum elasticity.

Results have shown inconsistencies for Necuron 1020 as the compressive elastic modulus and flexural modulus differ greatly. This could show that this is a material that behaves different at different loading conditions. To determine this further research needs to be done using different testing techniques and a bigger number of specimens and thus obtain statistical values.

The presence of defects determined a decrease in stiffness for all materials with approximately 5%. As expected, the defects caused a reduction in the compressive strength of Necuron 1020 and Necuron 1300. However, in case of Necuron 840, there was a higher compressive strength registered for specimens with

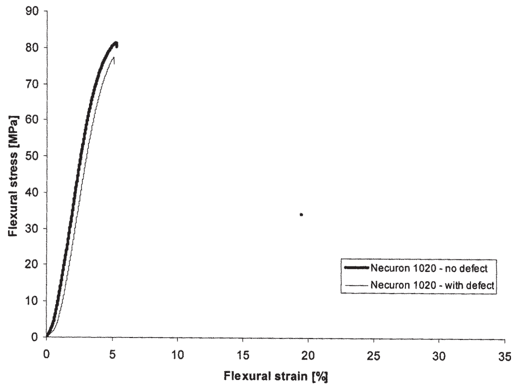

Fig. 7. Stress–strain curve of Necuron 1020 with and without defects

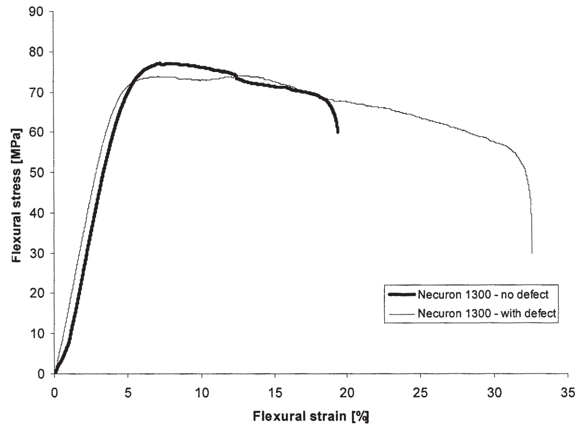

Fig. 8. Stress–strain curve of Necuron 1300 with and without defect

defects than the ones without. The flexural strength did not vary significantly as result of the presence of defects in case of all three materials.

Necuron 840 was the only material out of the three analyzed that did not exhibit an apparent yield point in compression. Furthermore, the same material was the only one that showed a greater maximum flexural strain in flawless condition than in the presence of defects. These two observations are consistent with a more rigid behaviour in compression and in bending for Necuron 840 than for the other two materials, also confirmed by the lower values of compressive and flexural moduli.

Conclusions

Mechanical characterization in bending and compression was carried out for three types of polyurethane materials: Necuron 840, Necuron 1020 and Necuron 1300, in order to determine which of the three materials is the most suitable to be used in transtibial prostheses. The influence of defects on the mechanical properties has also been analyzed and results show a decrease in elastic modulus for the flawed specimens. Furthermore, the results showed Necuron 840 has the most rigid behaviour in compression and bending. There were certain inconsistencies identified with regard to the behavior of Necuron 1020 and it has been determined that further testing is necessary to back up the obtained values. Finally, it has been concluded that Necuron 1300 is the most suitable to be used as a material for transtibial prostheses as it exhibits high compressive and flexural strength and optimum elasticity.

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.

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Manuscript received: 20.06.2014