A Study on the Use of Necuron-Type Polymer Plastics utilized for Sliding Bearing Manufacturing

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Received: 3 November 2024 | Revised: 29 November 2024 | Accepted: 10 December 2024

 DOI: https://doi.org/10.48084/etasr.9489

ABSTRACT

This paper presents research on the characteristics of the thermoplastic materials used in the manufacture of sliding bearings. Two types of materials from the category of thermosetting polyurethanes with the commercial names Necuron 1050 and Necuron 1300 were investigated. Tests were conducted to determine their physical and mechanical characteristics, such as density, hardness, tensile strength, compressive strength, and longitudinal modulus of elasticity. The results obtained during the study attest to the quality of the materials in the thermosetting polyurethane category in terms of hardness, tear resistance, and compression resistance. The materials in the category of thermosetting polyurethanes stand out as the right choice for applications that require mechanical strength, durability, and resistance to environmental factors.

Keywords- polyurethane; mechanical characteristics; sliding bearings; numerical model

I. INTRODUCTION

Plastic materials have a wide applicability because of their special physical and mechanical properties: low specific weight compared to steel and cast iron, high resistance to corrosion in various environments, low noise operation, bearings that do not require lubrication, low friction coefficient, and low energy consumption [1]–[3]. However, plastic materials are also affected by some unfavorable properties, such as low strength and its variation with temperature, deformability under loads owing to their low elasticity coefficient, high coefficient of thermal expansion, and lower thermal stability than metals [4].

In this context, a series of studies have been conducted to determine the physical and mechanical characteristics of plastic materials, such as Necuron, which are used for the manufacture of various components in the construction of machines [5–8]. Specifically, in [5], compression and three-point bending were performed on three types of Necuron, 840, 1020, and 1300, to evaluate their mechanical properties for use as materials for transtibial prostheses. In [6], the interaction between the microstructure and the mechanical characteristics of polymeric materials used in the automotive industry was investigated. Two categories of thermosetting polyurethanes Necuron 1020 and Necuron 1300 were studied. In [7], the mechanical properties of Necuron N651 and N1001, which are used to manufacture the components of the molds for rotor blades were presented.

The objective of the present study is to evaluate the use of Necuron material in the manufacture of sliding bearings. Two materials, Necuron 1050 and Necuron 1300, were tested in this study. To this end, an experimental procedure was carried out to obtain the mechanical properties of Necuron, starting from sampling, specimen fabrication, and testing to determine its mechanical characteristics. A secondary objective of this research was to better characterize the mechanical properties of the Necuron material because manufacturers' technical data sheets lack reliable information on material properties, and this information usually differs from one manufacturer to another [9–14].

II. METHODOLOGY AND TECHNICAL CONDITIONS FOR PERFORMING THE TESTS

The experimental procedure for determining the mechanical properties of the Necuron samples included the following types of mechanical tests: hardness, tensile, and compression tests. The measurements were carried out on specimens made of Necuron 1050 and Necuron 1300. The Necuron samples were supplied from Necumer GbmH, Bohmte, Germany.

A. *Density Tests*

The density of Necuron 1050 and Necuron 1300 was determined according to the ISO 1183-1:2019 standard. The samples were cube-shaped with a side of $l = 50$ mm, as can be seen in Figure 1. Seven samples of each material were analyzed. The working methodology consisted of determining the density of the material (ρ) as the ratio between the mass (m) and volume (V) of the investigated sample ($\rho = m/V$). The mass of each sample was determined by weighing. The weighing process was carried out with the help of the analytical balance KERN ALJ 310-4A, as illustrated in Figure 1, and with a precision of 10^{-4} g. The volume of each specimen was determined by multiplying the measured effective dimensions (l_1, l_2, l_3) of the cube ($V = l_i^3$, $i = 1,2,3$).

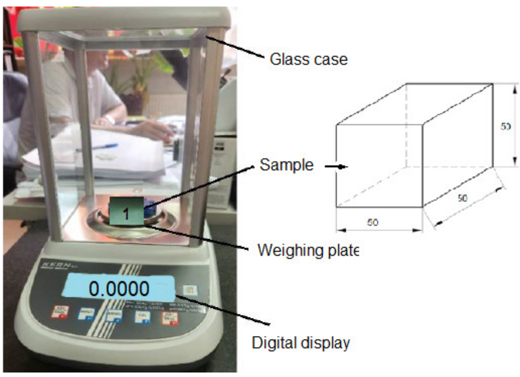

Fig. 1. The samples were weighed using an analytical balance (KERN ALJ 310-4A).

The lengths of the sides of the specimens were measured using a digital caliper with ± 0.01 mm accuracy. For each of the 7 studied samples ($P_1, P_2, ..., P_7$), the lengths (l_1, l_2, l_3) were measured, the volumes ($V_1, V_2, ..., V_7$) were calculated, and the samples were weighed ($m_1, m_2, ..., m_7$). Finally, the density of each sample ($\rho_1, \rho_2, \ldots, \rho_7$) was estimated and the arithmetic mean of the density values was determined for each material. The results are shown in Figure 2.

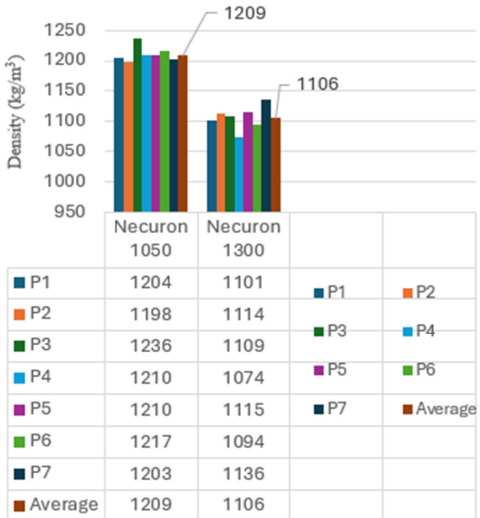

Fig. 2. Density values of Necuron 1050 and Necuron 1300.

B. *Hardness Tests*

The hardness was determined according to the ISO 868:2003 standard. The device used for the measurements was the Durometer Test Stand Model SLX – D, evidenced in Figure 3, exhibiting tolerance up to ± 2 HD. This device determines the hardness of plastic materials through penetration.

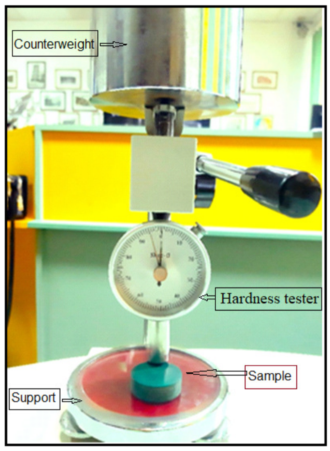

Fig. 3. The durometer test stand model SLX – D, which was used for measuring the Shore D hardness of the samples.

The tests were performed on disc-type specimens made from Necuron 1050 and Necuron 1300. The hardness was measured at seven points for each sample. The results are presented in Table I.

C. Tensile Tests

The tensile tests were performed according to the D638 ASTM test method for the tensile properties of plastics [15] and the ISO 527-1, 2019 standard [16]. The shapes and main dimensions of the samples are portrayed in Figure 4.

TABLE I. ESTIMATED HARDNESS OF NECURON SAMPLES

No. crt.	Shore D hardness	
	Necuron 1050	**Necuron 1300**
1	81	83
2	80	84
3	83	82
4	81	86
5	83	88
6	86	83
7	85	82
Average	83	84

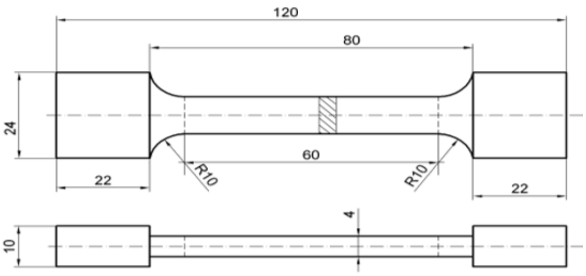

Fig. 4. Shape and main dimensions of the tensile test specimen.

Seven samples from each material category were tested, as displayed in Figure 5. The tests were performed using the LRX Plus plastic testing machine, illustrated in Figure 6, with a maximum load of 2.5 kN, 95% accuracy, and speed of 5 mm/min. The tests were performed at an ambient temperature of 21 °C.

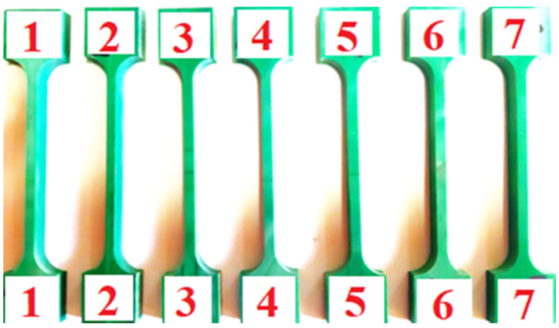

Fig. 5. Tensile test specimens.

The tensile measurements produced the characteristic force-displacement curves, shown in Figures 7 and 8, from which the mechanical characteristics were determined, as outlined in Table II: breaking strength (R_m), yield strength (R_c), elongation at break (A), and modulus of longitudinal elasticity (E). The values presented in Table II represent the average values derived from the measurements of the seven tested samples.

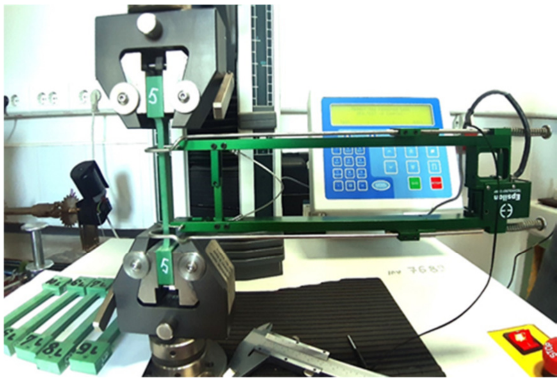

Fig. 6. Specimen subjected to the tensile test.

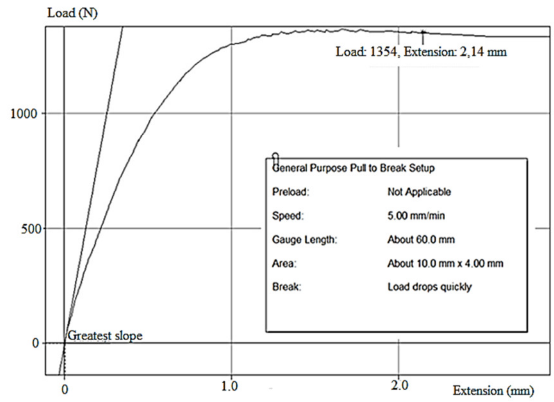

Fig. 7. Force-displacement characteristic curve for Necuron 1050.

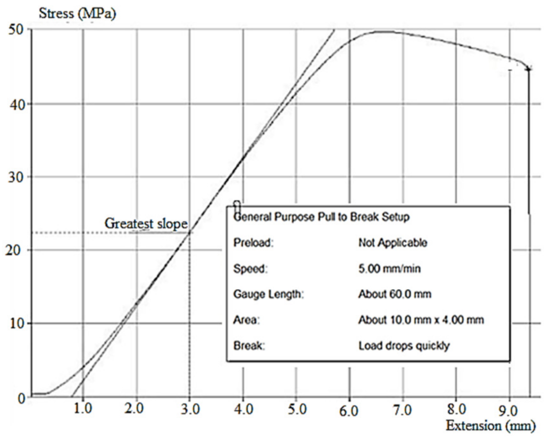

Fig. 8. Force-displacement characteristic curve for Necuron 1300.

TABLE II. MECHANICAL PROPERTIES OF NECURON 1050 AND NECURON 1300

Material type	Mechanical properties	Values
Necuron 1300	Tensile strength, R_m	51 MPa
	Yield strength, R_c	39 MPa
	Modulus of elasticity, E	2170 MPa
	Elongation at break, A	10 %
Necuron 1050	Tensile strength, R_m	35 MPa
	Yield strength, R_c	33 MPa
	Modulus of elasticity, E	2957 MPa
	Elongation at break, A	4,2 %

D. Compression Tests

Compression tests were performed on the two Necuron materials. These experiments are necessary in order to establish the behavior of the materials under stress when used in sliding bearings. The compression tests were performed according to the ASTM D695-23 protocol [17] on specimens having the shape and dimensions shown in Figure 9.

Compression tests were performed on 10 samples for each of the Necuron 1050 and Necuron 1300 materials. The specimens were tested on a Walter Bai LF 300 universal machine, specialized for static and dynamic tests, with a load capacity of up to 300 kN in static mode, as seen in Figure 10.

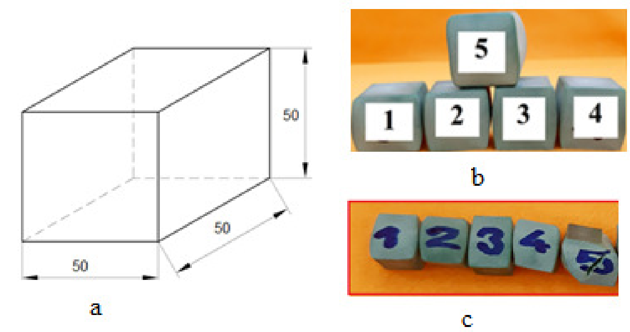

Fig. 9. Necuron 1050 compression test specimens: (a) geometric characteristics, (b) before compression stress, (c) after compression stress.

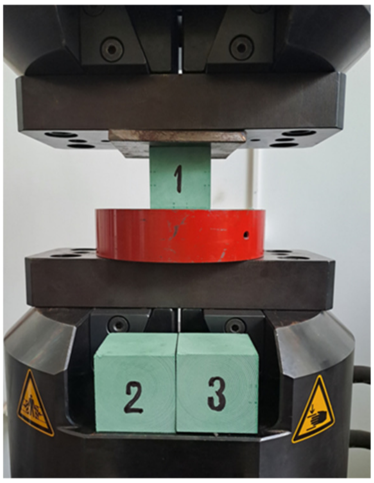

Fig. 10. The specimens were subjected to compression tests using a Walter Bai LF300 universal machine.

The tests were performed in the static mode. The loading speed was 5 mm/min. The tests were carried out at an ambient temperature of 21 °C. Figures 11 and 12 display the force–deformation curves from which the modulus of elasticity in compression, strength in compression, and yield strength in compression were determined, as shown in Table III.

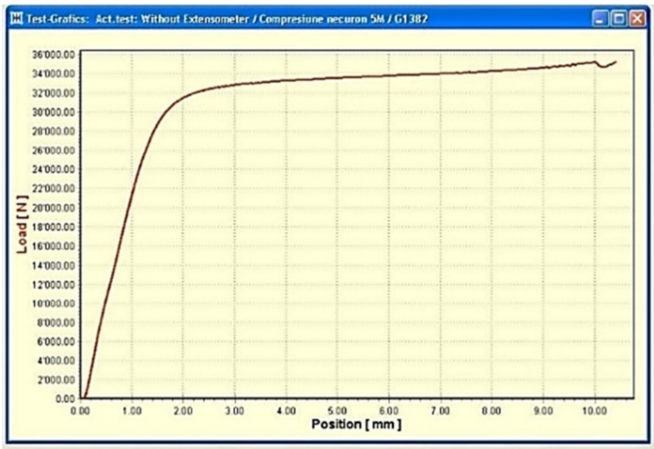

Fig. 11. Force-deformation diagram of Necuron 1050.

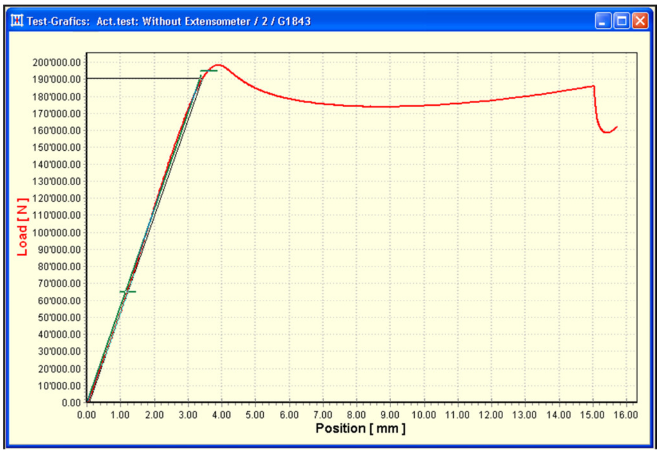

Fig. 12. Force-deformation diagram of Necuron 1300.

The values presented in Table III represent the average values of the 10 tested samples.

TABLE III. MECHANICAL CHARACTERISTICS IN COMPRESSION

Material type	Mechanical properties	Values
Necuron 1300	Compressive strength, R_m	84 MPa
	Compressive yield strength, R_c	68 MPa
	Modulus of elasticity in compression, E	2674 MPa
Necuron 1050	Compressive strength, R_m	72 MPa
	Compressive yield strength, R_c	67 MPa
	Modulus of elasticity in compression, E	2542 MPa

III. NUMERICAL SIMULATION OF MECHANICAL TESTS

This section outlines a simulation approach designed to compare the stress-strain curves obtained through experiments with those generated by numerical simulations. The numerical simulation involved creating a Finite Element Method (FEM) model that could accurately represent the process results and identify solutions to resolve or optimize the experimental results [18–23].

The FEM simulations were performed using the ANSYS software. In this context, simulations were carried out for the tensile test of the Necuron 1050 material. This required the transformation of the force-elongation curve into a force-elongation curve based on discrete values obtained experimentally. Hence, plasticity with isotropic hardening was selected as the material model. Using this model, the ANSYS software accepted the input of the experimentally obtained curve.

Figure 13 demonstrates the stress state obtained by modeling with the ANSYS software (tetrahedral finite element type) for the experimental test shown in Figure 7.

Figure 14 depicts the comparison between the experimentally obtained force-deformation curve, observed in Figure 7, and the similar curve resulting from numerical model using the FEM for Necuron 1050.

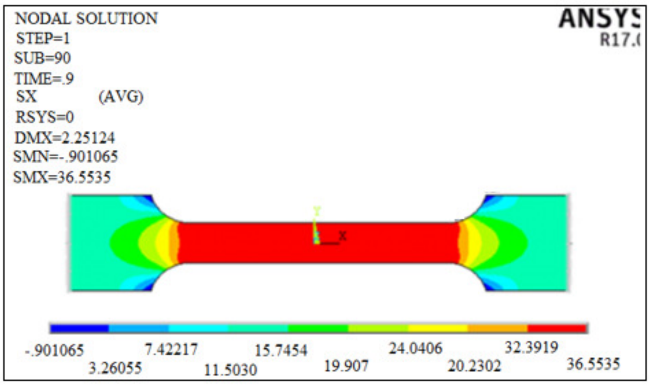

Fig. 13. Stress state obtained by modeling with ANSYS software.

Figure 14 compares the experimental and simulated force displacement curves that have similar configurations. Although the two curves exhibit similar behaviors, a small deviation was observed.

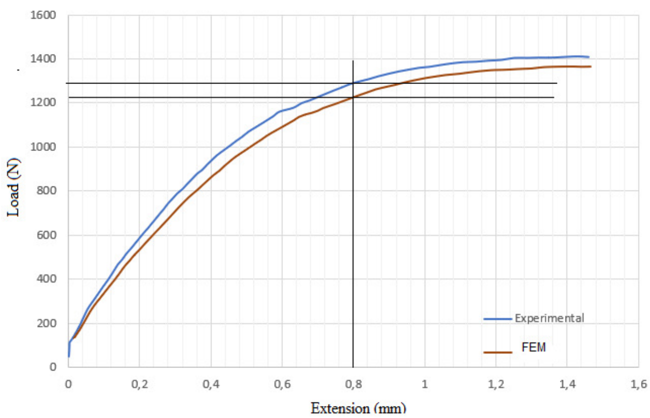

Fig. 14. Comparison between the force-deformation curve obtained experimentally and that obtained from the numerical simulation.

IV. RESULTS AND DISCUSSION

For the experimental study of the characteristics related to the use of Necuron-type polymer plastics for the manufacture of sliding bearings, experimental determinations were carried out to determine the density, hardness, static tensile test, and compression test.

The conducted studies and research led to the following conclusions. Regarding the determination of the density of the materials, the average values obtained ($\rho_{Necuron1050}$ = 1209 kg/m^3, $\rho_{Necuron1300}$ = 1106 kg/m^3) were consistent with those in specialized literature: $\rho_{Necuron1300}$ = 1150 kg/m^3 [6], $\rho_{Necuron1300}$ = 1150 kg/m^3 [24], $\rho_{Necuron1300}$ = 1109 kg/m^3 [25], and $\rho_{Necuron1300}$ = 1100 kg/m^3 [11].

The hardness was determined for disc-type samples manufactured from Necuron 1050 and Necuron 1300. Seven samples of each type of material were used. The results of the experimental research confirm the average values $D_{Necuron,1050}$ = 83 Shore D and $D_{Necuron,1300}$ = 84 Shore D, which fall into the extra hard category Shore D. For the samples made of Necuron 1300, compared to Necuron 1050, a slight increase in hardness was noted, and the average value obtained was higher by one Shore D unit. The high hardness values of the studied materials indicate that they can be used in the manufacturing of sliding bearings. In the specialized literature, research was carried out on the determination of hardness, obtaining the following values: $D_{Necuron,1300}$ = approx. 80 Shore D [11], $D_{Necuron,1300}$ = approx. 86 Shore D [10], and $D_{Necuron,1050}$ = approx. 80 Shore D [12]. From the comparison of the results, it is evident that the differences in the hardness values obtained through our own studies compared to other bibliographic sources are not significant and can be explained by the variations in both the chemical composition and structure of the material. The hardness of Necuron 1300 is slightly higher than that of Necuron 1050.

The mechanical tests performed on the samples made with the two polymer materials, Necuron 1300 and Necuron 1050, highlighted the values of the resistance and compression characteristics, which were compared with the results from the specialized literature. Thus, for the tensile strength test, evidenced in Table II, the values that were obtained for Necuron 1300 were $R_{m,Necuron\ 1300}$ = 51 MPa, $R_{c,Necuron1300}$ = 39 MPa, $E_{,Necuron1300}$ = 2170 MPa, and $A_{,Necuron1300}$ = 10 %, while for Necuron 1050, we get $R_{m,Necuron1050}$ = 35 MPa, $R_{c,Necuron1050}$ = 33 MPa, $E_{,Necuron1050}$ = 2957 MPa, and $A_{,Necuron1050}$ = 4.2 %. Comparing the results, it is observed that R_m, R_c, and A were higher in Necuron 1300. However, Necuron 1300 exhibited a lower E value than Necuron 1050. For comparison, in the literature the R_m, R_c, E, and A where found for Necuron 1300: $R_{m,Necuron1300}$ = 47.10 MPa [6], $R_{c,Necuron,1300}$ = 39.36 MPa, $E_{,Necuron1300}$ = 2317 MPa, $A_{,Necuron1300}$ = 6.60 %, [24], $R_{m,Necuron1300}$ = 53 MPa, $R_{c,Necuron1300}$ = 47.40 MPa, $E_{,Necuron1300}$ = 693.30 MPa [12], $R_{m,Necuron1300}$ = 49 MPa, $R_{c,Necuron1300}$ = 37 MPa, $E_{,Necuron1300}$ = 2753 MPa, and $A_{,Necuron1300}$ = 12 % [13]. Equivalently, for Necuron 1050: $R_{m,Necuron1050}$ = 38 MPa, $R_{c,Necuron1050}$ = 30 MPa, $E_{,Necuron1050}$ = 3247 MPa, and $A_{,Necuron1050}$ = 2.60 % [13]. Considering the values presented in the literature compared to those obtained through the present study's experimental determinations, for R_m, there is a percentage decrease of 7.80%, for R_c, a percentage increase of 10%, for the modulus of elasticity E, a percentage decrease of 8.90%, and for elongation A, a percentage increase of 7.60%.

Regarding the compression test, the results of the experimental research led to the following values Table III) for Necuron 1300: $R_{m,Necuron1300}$ = 84 MPa, $R_{c,Necuron1300}$ = 68 MPa, and $E_{,Necuron1300}$ = 2674 MPa. For Necuron 1050: $R_{m,Necuron1050}$ = 72 MPa, $R_{c,Necuron1050}$ = 67 MPa, and $E_{,Necuron1050}$ = 2542 MPa. Comparing the results obtained for Necuron 1300 in relation to Necuron 1050, for R_m, there was a percentage decrease of 14.20%, for R_c, a percentage decrease of 1.40%, and for the modulus of elasticity E, a percentage decrease of 4.90%. The data presented in the specialized literature show the values for Necuron 1300: $R_{m,Necuron1300}$ = 51 MPa, $R_{c,Necuron1300}$ = 39 MPa, $E_{,Necuron1300}$ = 2170 MPa, and $A_{,Necuron1300}$ = 10%, respectively. For Necuron 1050: $R_{m,Necuron1050}$ = 35 MPa, $R_{c,Necuron1050}$ = 33 MPa, $E_{,Necuron1050}$ = 2957 MPa, and $A_{,Necuron1050}$ = 4.20%.

The numerical simulation carried out for the tensile tests of Necuron 1050 consisted of the generation of an FEM model capable of describing the results of the actual process of experimental determinations. For this purpose, for the force-deformation curve obtained experimentally, the curve resulting from the numerical simulation was associated. In this way, the present work aimed to establish how the choice of the types of links and the discretization of the model lead to optimization to obtain results as close as possible to those of the actual experiment. Modeling was performed using the ANSYS program. This required the transformation of the experimentally obtained force-strain curve, the experimental curve displayed in Figure 14, into a specific stress-strain curve obtained by numerical modeling, FEM curve in Figure 14. If the deformation d = 0.80 mm is considered, according to Figure 14, then the following values of the loading force are obtained: for the experimental curve F_{exp} = 1286 N and for the curve obtained by numerical modeling F_{FEM} = 1218 N. In this case, the relative error was 5.20%. Through the optimizations performed on the discretization elements, that is, the links between the elements, smaller errors can be obtained that lead, in the end, to the overlap of the two analyzed curves (theoretically). Thus, the uncertainties associated with the FEM model include differences between the behavior obtained by the numerical model and the actual behavior of the structure. In practice, this error can be reduced but not eliminated.

Regarding the stress state of the specimens tested in tension and those obtained by FEM, the following conclusions can be drawn. During the tensile test of the Necuron 1050 specimen, the maximum force recorded was $F_{max,exp}$ = 1372 N (Figure 7). In this case the maximum stress value is $\sigma_{max,exp} = F_{max,exp}/S$ = 1372/40 = 34.30 N/mm^2, where S represents the section of the test specimen, S = (10 × 4) mm^2. Through the numerical simulation, the maximum stress $\sigma_{max,\ FEM}$ = 36.55 N/mm^2 was obtained (Figure 13). The relative percentage error in this case was 6.10%.

V. CONCLUSIONS

Necuron-type polymeric plastic materials are produced in a wide range of types, presented in the catalogues of different manufacturers. The objective of this study was to establish the physical-mechanical characteristics of plastic materials from the polyurethane category by analyzing two materials with the trade names Necuron 1050 and Necuron 1300.

For the experimental study of the characteristics related to the use of Necuron-type polymer plastics for the manufacture of sliding bearings, experiments were carried out to determine the density, hardness, and their static tensile and compression behavior. The results obtained experimentally prove that the two categories of the studied materials have properties that make them suitable for the manufacturing of sliding bearings. Finally, it can be concluded that Necuron 1300 is more suitable to be used as a material for sliding bearings because it exhibits high hardness and compressive strength.

Plastics are of great interest for the construction of sliding bearings owing to their low cost and good anti-friction properties. This category of materials has seen wide application in recent decades due to their special properties: low specific gravity compared to steel and cast iron, high corrosion resistance in various environments, high plasticity, some bearings do not require lubrication, some materials can be environmentally friendly, low friction coefficient, low noise operation, high productivity processing technology with reduced operations, and low energy consumption. Among their disadvantages are low reliability, low resistance to high temperatures, and low dimensional accuracy.

The results of the research carried out in this work attest to the strength characteristics of Necuron 1050 and 1300 materials, which are close to those of the non-ferrous materials (Cu-Pb alloys SR EN 1982:2008, with hardness HB 23 = 45) used in the manufacture of plain bearing bushings.

ACKNOWLEDGMENT

All samples were made and tested in the laboratories of the Mechanical Engineering Department of the Petroleum-Gas University of Ploiesti.

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