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THE EFFECT OF CONDITIONING UPON THE MECHANICAL PROPERTIES OF POLYAMIDE

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S u m m a r y

Polyamide is one of the basic engineering polymeric materials. It is used in many varieties which are characterized by different properties. Conditioning this material is necessary to obtain suitable mechanical properties. In this paper the results of strength testing of both unfilled and filled with 30% glass fiber polyamide 6 and the effect of duration of water conditioning upon the mechanical properties are presented.

Keywords: polymeric materials, polyamide, conditioning, mechanical properties

Wpływ kondycjonowania poliamidu na zmianę właściwości mechanicznych

S t r e s z c z e n i e

Poliamid jest jednym z podstawowych materiałów polimerowych inżynierii. Stosowany jest w wielu odmianach, które charakteryzują się różnymi właściwościami. W celu uzyskania odpowiednich właściwości mechanicznych napełnia się go włóknem szklanym, które znacząco podnosi wytrzymałość, ale również stosuje się kondycjonowanie w wodzie o odpowiedniej temperaturze, które nie pozostaje bez wpływu na właściwości gotowego wyrobu.

Słowa kluczowe: materiały polimerowe, poliamid, kondycjonowanie, właściwości mechaniczne

1. Introduction

Polymeric materials, commonly known as plastics, are used in all fields of both daily applications and advanced technology. The good strength to density ratio makes them competitive to many non-iron metals. Moreover the amount of energy needed to manufacture a final product is definitively smaller than it is in case of steel or aluminum. Polymer processing is characterized by low energy and material consumption. The manufactured items are environmental friendly and recyclable.

Polyamide is an engineering polymeric material of good mechanical properties and functional quality. It is a thermoplastic polymer, containing in its main chain the amide groups -CO-NH-. In the denotation of polyamides (eg. polyamide 6, polyamide 6.6, polyamide 6. 10) the single digit means that it is

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polymerized from V-amino acid or lactam and denotes the number of carbon atoms in the amino acid. Two digits mean that it is the product of di-amine and di- acid polymerization The first digit denotes the number of methylene groups in di-amine, the second – the number of carbon atoms in di-acid respectively [1-4].

Polyamides are partly crystalline, that is why the manufactured items are more or less transparent depending on the wall thickness. The very important property of polyamides is water absorption which has a strong effect on their mechanical properties. A "dry" material is very brittle; its impact strength is low which is accompanied by high tensile strength. With the increase of water content its toughness and flexibility increases while the tensile strength drops a little [1-4].

Due to their properties, polyamides are used in mechanical engineering. Their main advantages in this aspect are: resistance to many chemicals [4-6], mechanical strength and the possibility of easy modifying by adding suitable fillers [7-9]. The final properties of polyamide are determined by water conditioning which takes place above the ambient temperature. In order to obtain the desired properties of the material the time and the temperature of the water bath must be observed [10-13].

That is why the results of strength testing of both unfilled and filled with 30% glass fiber polyamide 6 and the effect of duration and temperature of water conditioning upon the mechanical properties are presented in this paper.

2. Materials and specimens

Two kinds of polyamide were tested: Schulamid 6 MV HI K1884 (unfilled) and Schulamid 6 GF 30 (filled with 30% glass fiber). For mechanical testing, the paddle shaped and beam shaped specimens were injection moulded in accordance with the standards. The purpose of glass fiber admixture was to improve the mechanical properties, mainly the impact strength.

The specimens were conditioned in water. Due to various conditioning parameters (temperature and duration) four combinations of the parameters for both materials were applied. Apart from the non conditioned material (referred to as zero test), two values of temperature (20 and 95°C) and two duration times (4 and 8 hours) were applied.

3. Testing

The tensile strength testing was performed in accordance with the standard PN-EN ISO 527-2:2012, the determination of hardness - in accordance with the standard PN-EN ISO 2039-1:2004 and the Charpy impact strength testing – in accordance with standard PN EN ISO 179-1:2010 respectively.

The humidity of the material (the water content in the final product) was also determined according to [14]. It consisted in taking the weight of the conditioned specimens before drying and after 6 hour drying in the at the determined temperature.

4. Tensile strength

After the conditioning was completed, all specimens underwent the test on a tensile strength tester. The maximum stress and the corresponding strain were recorded. In Table 1 the results for the unfilled polyamide are presented. The same can be seen in Fig. 1 and 2.

Table 1. Maximum stress and corresponding strain for unfilled polyamide

No.	**Conditioning temperature, °C**	**Time of water conditioning, h**	**Stress, MPa**	**Strain, 1**
1	Zero test		30.7	0.26
2	20	4	30.3	0.24
3	20	8	52.4	0.29
4	95	4	26.4	0.34
5	95	8	50.0	0.40

Figure 1 shows that the maximum stress depends mainly on the conditioning time, not on the temperature. The rise of 20 MPa compared to the zero test (non-conditioned specimens) is remarkable.

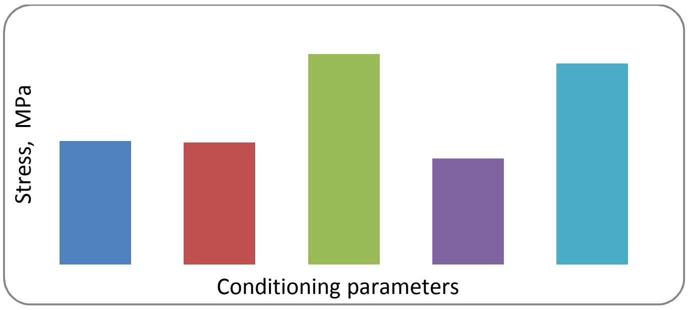

Fig. 1. Maximum stress for the unfilled polyamide

Figure 2 presents the results for the strain at maximum stress which will be referred to as maximum strain. It can be seen that both the conditioning temperature and the time cause the rise of the maximum strain. The effect seen in Fig. 2 is known in the literature and can be explained by water penetrating into the macromolecule chains of the amorphous phase. The water acts in a way as a “plasticizer” increasing the distance between the molecules (the entire item made of polyamide swollens) and thus enabling the molecules to shift more smoothly against one another.

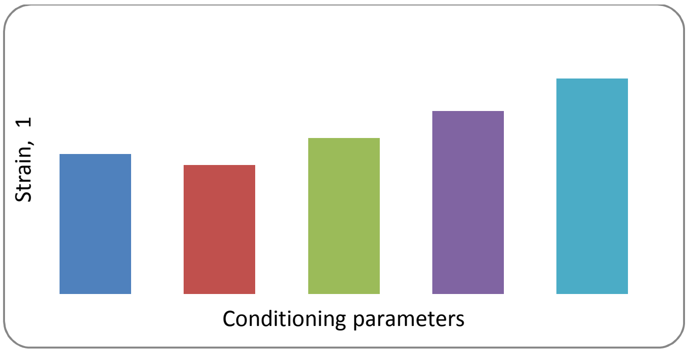

Fig. 2. Maximum strain for the unfilled polyamide

The same tensile tests were performed for the polyamide filled with 30% glass fiber. The results are presented in Tab. 2 and in Fig. 3 and 4.

Table 2. Maximum stress and corresponding strain for polyamide filled with 30% glass fiber

No.	Conditioning temperature, °C	Time of water conditioning, h	Stress, MPa	Strain, l
1	Zero test		153.3	0.26
2	20	4	148.3	0.24
3	20	8	164.7	0.29
4	95	4	129.3	0.34
5	95	8	119.0	0.40

For the maximum stress the results are completely different than for the unfilled material. Generally, conditioning lowers the strength of the materials instead of rising it, while maximum strain remains practically unchanged. It is due to the function of the fibers which are not sensitive to water and thus remain unchanged no matter how the thermoplastic matrix is conditioned. The variations seen in Fig. 3 and 4 are slight fluctuations which are probably within the range of the measurement error.

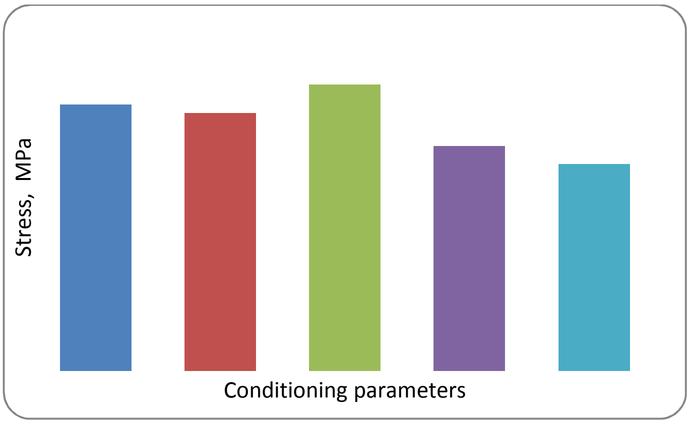

Fig. 3. Maximum stress for the polyamide filled with 30% glass fiber

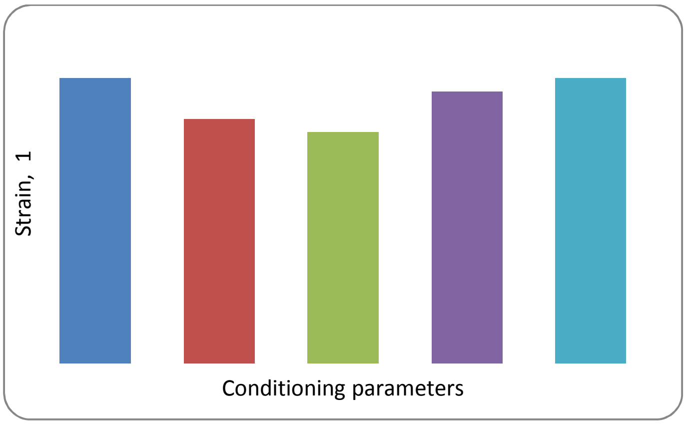

Fig. 4. Maximum strain for the polyamide filled with 30% glass fiber

5. Hardness

The test consists of pressing a ball shaped penetrator of 5 mm diameter during 30 seconds into the material. The balance between the increasing pit area and the pressing force determines hardness of the material. The results are shown in Table 3 and in Fig. 5 and 6. It can be seen that for the unfilled polyamide the influence of both time and temperature of conditioning is remarkable and cause the decrease of hardness. It coincides with the maximum strain (Fig. 2). The higher the water content, the more flexible is the material which, in turn means lower rigidity and hardness. For the GF-reinforced polyamide the influence of conditioning is rather poor with the unexpected peak for 20°C and 8 hours which is difficult to explain at the basic stage.

Table 3. Average hardness of the unfilled and the filled polyamide.

Lp.	Parameters of conditioning	Hardness of the unfilled PA, MPa	Hardness of the filled PA, MPa
1	Zero test	38.6	89.8
2	20°C; 4h	43.2	81.3
3	20°C; 8h	35.3	107.8
4	95°C; 4h	30.9	72.4
5	95°C; 8h	16.2	76.3

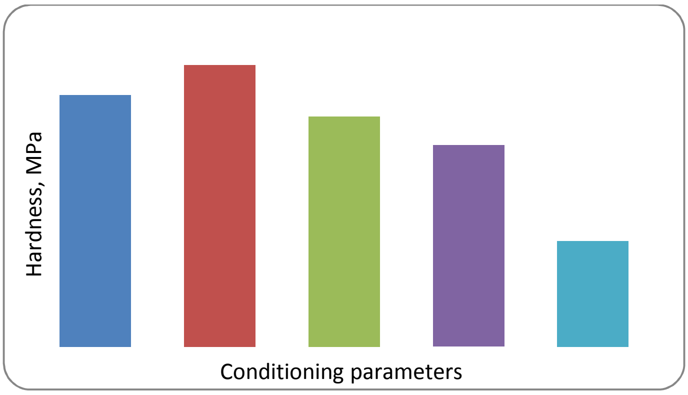

Fig. 5. Hardness of the unfilled polyamide.

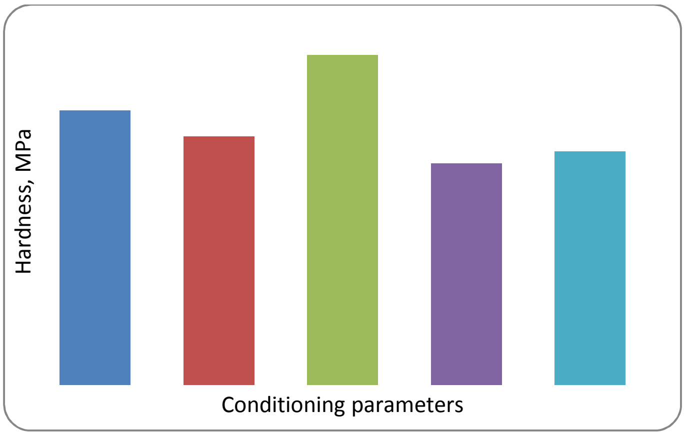

Fig. 6. Hardness of the filled polyamide

6. Impact strength

The impact tests were performed in accordance with the Charpy testing standards with the help of the pendular hammer of the energy 5 kJ.

The specimens made of the unfilled polyamide did not break; they remained only bent instead. Such measurements cannot be taken into account. So only for the filled polyamide the test was valid even though not all specimens broke. It means that generally this material is very tough. In Table 4 and in Fig. 7 the results for the filled material are presented.

Table 4. Impact strength of the filled polyamide

No	**Parameters of conditioning**	**Impact strength, kJ/m^2**
1	Zero test	98.6
2	20°C; 4h	87.5
3	20°C; 8h	87.5
4	95°C; 4h	92.6
5	95°C; 8h	95.0

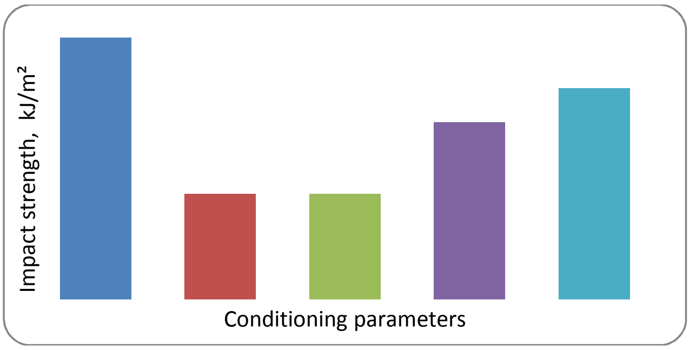

Fig. 7. Impact strength of the filled polyamide

Figure 7 shows that compared to the zero test, both temperature and time of conditioning cause the rise of the impact strength after the initial drop. The rise can be explained by the toughening of the polyamide matrix while the initial drop is probably the result of the water enabling for easier pulling the fibers out of the matrix. This effect is very strong and finally the impact strength of the GP-filled polyamide is worse after being conditioned than it is if not being conditioned at all (zero test), no matter what the conditioning parameters are.

7. Conclusions

Water conditioning is an important factor determining the mechanical properties of Polyamide 6. For the unfilled polymer, the content of water significantly rises its flexibility which in turn affects its deformability which rises and its hardness which slightly drops.

The polymer filled with 30% glass fiber is not very sensitive to the water content. It is due to the fact that the fibers play the major role in the mechanical behaviour of the material an thus the changes of the polymer matrix are negligible.

The results of the impact strength testing are a bit astonishing. The unfilled material does not break so there can be no valid results. For the filled material, water conditioning rises the impact strength but after the initial drop compared to zero test. It is probably due to the improvement of the polymeric matrix. Yet the rise of the matrix toughness does not compensate the drop of the force needed to pull the fibers out of the matrix. Finally, the water conditioning worsens the impact strength of the glass filled polyamide.

The final conclusion is that water conditioning is important only for the unfilled polyamide. In case of the filled material it is better to remain it unconditioned.

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