Article

Experimental testing of material Mosten GB 005 on various concentration of recycled material

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Abstract: Main objective of presented scientific article is to define mechanical properties of polypropylene Mosten GB 005 in dependence on prescribed precentral ratio of recycled regranulate. Polypropylene Mosten GB 005 is a general purpose homopolymer, intended for injection molding and for production of thermoforming films. It can be also used for production of various compounds. Experimental verification of mechanical properties was realized by testing samples produced with various concentrations of the recycled material. Experimental samples were realized undergo tests to obtain mechanical properties of produced new material (on these tests were realized and evaluated rheological tests, tensile and flexural tests as well as hardness and Charpy impact toughness tests). Experimental samples were divided into 7 classes depend on percentage ratio of added recycled material into raw material concretely 0%,10%,20%,30%,50%,70% a 100 %. Mentioned mechanical tests were realized according to ISO standards valid for individual testing method. Each testing method was carried out using prescribed numbers of testing samples. The flexure test was realized on five experimental testing samples and subsequent tests were carried out on ten experimental samples from each class of produced material. Presented scientific article is also focused on changes in microstructures of testing materials in depends on percentage ratio of recycled regranulate. Recycled regranulate of thermoplastic was not necessity to additionally modify. Presented article also contain experimental verification of thermal properties using Differential Scanning Calorimetry (DSC).

Keywords: Mosten, Polymer, Recyclate, Mechanical properties, Calorimetry

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1. Introduction

Thermoplastic injection technology iscurently among the most commonly used plastics processing technologies and production of plastic products. Thanks to the wide range of uses thermoplastics, especially in the automotive, electronics and other areas of industry, the technology is perspective ahead. There are many factors affecting the final quality of plastic products. The most significant factors affecting the quality of final products include technological parameters of injection molding machine, which are directly related to the production process. The production process of injection molding is affected by a number of parameters which are interrelated and interdependent [1][2][3].

Presented paper is focused on monitoring the impact of changes in the basic technological parameters, melt and the switching point for the duration of the injection cycle and the final quality of injection-molded products using a computer simulation of the injection process. Also at work is evaluated significance of the effect of these basic parameters to the observed values [4].

Among the biggest disadvantage of plastics is their long life, which has a negative impact on the environment. Efforts of manufacturers is to implement back in the production of plastics in the form of recycled or of regranulate. Evaluating the quality of products made of materials containing regranulate is possible only by experimental research[5][6].

Plastics can be defined as macromolecular substance which can be shaped by heat or pressure, or both agents simultaneously [7].

The various types of plastics have their distinctive, functional and processing properties. They may be partially varied or adjusted using of additives. From a functional perspective is evaluated mainly[8]:

- mechanical strength for long-term or short-term static and dynamic loads,
- electrical properties such as dielectric strength, conductivity etc.,
- chemical resistance to various chemical agents, for food industry,
- optical properties such as the transparency, color, gloss etc.

Processing aspect is equally important. Significant properties:

- the fluidity, which affects critical wall thickness of product, concept of the molding and size of the inlet and also affects tempering of the mold (optimum temperature of the tool in relation to the processing of plastics, construction and technological parameters).
- Shrink size, which determines the accuracy of product manufacturing
- sensitivity to technological parameters of manufacturing equipment and etc.

Base dividing of plastic polymers for injection is described in table 1.

Table. 1 polymer materials [9]

POLYMERS			
REAKTOPLASTIC	*TERMOPLASTIC*	*TERMOPLASTIC ELASTOMERS*	*ELASTOMERS*
phenol	Partially crystals	High hardness	NR
melamine	amorphous	Low hardness	SBR
epoxy			NBS
polyester			EPDM
others			other

For enhancement of polymeric materials processing, the most common additives are added to the polymer:

Injection molding is a cyclic process with the average cycle timefrom 15 to 120 seconds for thermoplastics. The cycle time depends on the size and properties of the polymer product. Product weight ranges from a few grams to 25 kg [10].

The process of injection is as follows: granular plastics are supplied to a hopper from which is collected to injection machine working parts (piston, screw), which transports the material into the melting chamber, where at simultaneous action of friction and temerature plastic melts. The melted mass is injected into the mold cavity, which completely fill and assume the shape. Compression stage follows to reduce the shrinkage and dimensional changes. Plastic transmit heat to mold and cooling solidifies into the final product. In final stage the mold is opened and product is ejected and the cycle is repeated (Fig. 1) [11] [12].

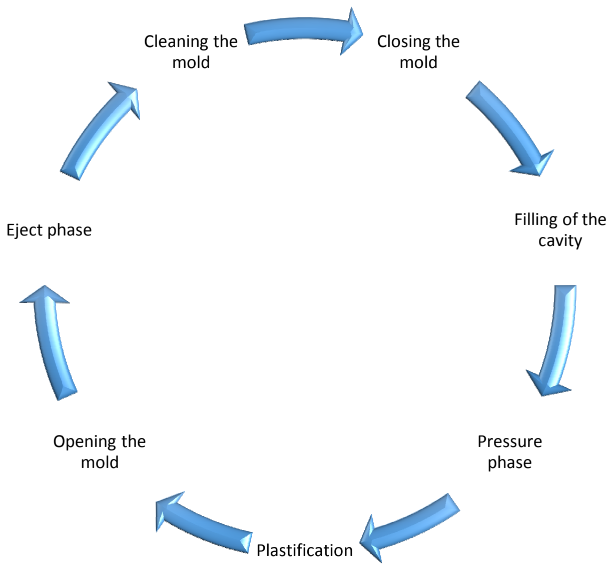

Figure. 1 Schematic of injection process

2. Experimental part

Experimental samples were produced on Department of engineering technologies Technical University in Liberec. As experimental material was selected Mosten GB 005 (polypropylene, homopolymer) and experimental samples were produced on injection press ENGEL Victory 80/25 (Fig. 2) [6].

Technological parameters preset was according to material data sheets of selected material. Mechanical properties are shown in following table (Tab . 2)

Table. 2 Mechanical properties of MOSTEN GB 005

Properties	Unit	Mosten GB 005	Standard
Melt mass flow rate MFR	*g/10 min*	(230 ^{0}C, 2,16 kg) 5,0	*ISO 1133*
Yield strength	*MPa*	34	*ISO 527-2*
Density	*g.cm^{-3}*	0,908	*ISO 1183*
Flexural modulus	*MPa*	1550	*ISO 178*
Notch toughness CHARPY (23 ^{o}C)	*kJ.m^{-2}*	4	*ISO 179*
Softening temperature according to Vicat	*^{o}C*	157	*ISO 306*

Figure. 2 Engel Victory 80/25

Testing samples were divided to 7 classes according to percentage ratiorecyclate/base material as follows:

Skúšobné telesá sa rozdelili do 7 šarží, ktoré boli v závislosti od pomeru regranulát/základný materiál označované nasledujúcim spôsobom:

1 - 0% - base material
2 - 10% - content of recyclate
3 - 20% - content of recyclate
4 - 30% - content of recyclate
5 - 50% - content of recyclate
6 - 70% - content of recyclate
7 - 100% - recyclate

Experimental procedure was performed according to appropriate standards for each type of test. Flexural properties test was made on 5 samples, remaining tests were made on 10 samples.

Realized tests:

- Test of rheological properties EN ISO 1133:2006
- Hardness test EN ISO 868:2003
- Impact strength (Notch toughness) EN ISO 179-1/1eU (EN ISO 179-1/1eA)
- Test of flexural properties EN ISO 178:203

Rheological properties testing were performed according to EN ISO 1133:2006 using pastometer CEAST. Experimental samples with precentral ratio from 0% to 100% as mentioned upper were tested for parameter Melt mass flow rate (MVR) cm3/10 min, which describes flow properties of plastic materials. In MVR testing is plastic material pressed trough capillary with diameter 2,095 mm and 8 mm length. For each class were performed 10 measurements and subsequently calculated average value and created graphical dependence.

Experimental conditions for MOSTEN GB 005 :

- Melting chamber temperature – 230 °C
- Nominal load – 2,16 kg
- Length of piston – 25 mm

Following figure (fig. 3) shows graphical dependence of MVR on precental ratio of recyclate.

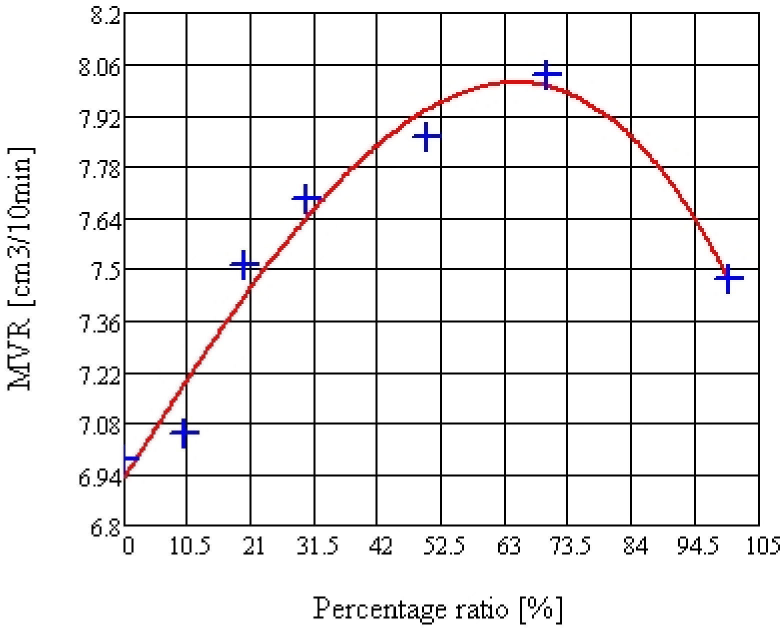

Figure. 3 Graphical dependence of MVR on percentage ratio of the recyclate

$$MVR = -1{,}7.10^{-6}.x^3 - 3{,}29.10^{-5}.x^2 + 0{,}026.x + 6{,}93$$

Where: MVR - Melt flow rate
x - percentage of recycled granulate

Correlation index of measured (blue points) and calculated (red curve) values is 97,89 %, dispersion is 0,1313 and standard deviation was calculated 0,36. Calculation was realized based on following assumptions and equations. Let X be a random variable, which takes the final or countless many values. Then we define dispersion as:

$$VAR[X] = \frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1} \text{ and deviation is } DEV[X] = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1}}$$

Measured values of MVR are shown in table 3.

Table. 3 Measured values of MVR for material Mosten GB005

Sample	Number of material class – percentral ratio of recycled material [cm^3/10min.]						
	1 - 0%	**2 - 10%**	**3 - 20%**	**4 - 30%**	**5 - 50%**	**6 - 70%**	**7 -100%**
1	6,90	6,95	7,31	7,53	7,70	7,86	7,25
2	6,92	6,96	7,44	7,58	7,83	7,88	7,29
3	7,02	7,09	7,46	7,53	7,83	7,98	7,35
4	7,03	7,05	7,41	7,69	7,81	8,00	7,41
5	7,00	7,15	7,48	7,74	7,81	8,00	7,43
6	6,97	7,02	7,56	7,81	7,90	8,07	7,48
7	7,00	7,05	7,58	7,79	8,07	8,09	7,56
8	7,02	7,11	7,58	7,82	7,98	8,15	7,67
9	7,01	7,15	7,62	7,77	7,88	8,16	7,72
10	7,05	7,22	7,61	7,79	7,80	8,15	7,63
Average	**6,98**	**7,05**	**7,51**	**7,69**	**7,86**	**8,03**	**7,47**

Based on results of MVR shown upper (fig.29) can be stated, that material class no.1 achieves lowest value of MVR 6,98 cm3/10 min. Pure material containing no regranulate passes through the capillary at the time the smallest amount of melt. The addition of 10% regrind into the base material (classno. 2) MVR slightly increased. For materials class no. 3 MVR was an increase of 0.46 cm3/10 min compared to the material class no. 2. The gradual increase was recorded for a material with regranulate containing 30%, 50% and 70% (class no. 4, 5 and 6) which is also evident from the graph. Material class no. 7 (regranulate100%) showed a decrease in the values MVR average of 0.50 cm3/10 min compared to the material class no. 6th

Tensile properties testing were performed using tensile machine Hounsfield H10KT and software QMat according to standard STN EN ISO 527 – 1,2. For each class were performed 10 measurements and subsequently calculated average value and created graphical dependence.

Evaluated tensile properties parameters:

- Yield stress σy [MPa]
- Nominal elongation εt [%]
- Nominal elongation at fracture εtB [%]
- Tensile strength at fracture σB [MPa]

Conditions of tensile properties testing for MOSTEN GB 005:

- measured without preloading
- sensor head 10 kN
- initial distance between jaws Lo = 102 mm.

Granule termoplastu nebolo potrebné pred vstrekovaním špeciálne upravovať.

- Yield stress σy [MPa]

Figure 4 shows graphical dependence of yield stress for various ratio of regranulate.

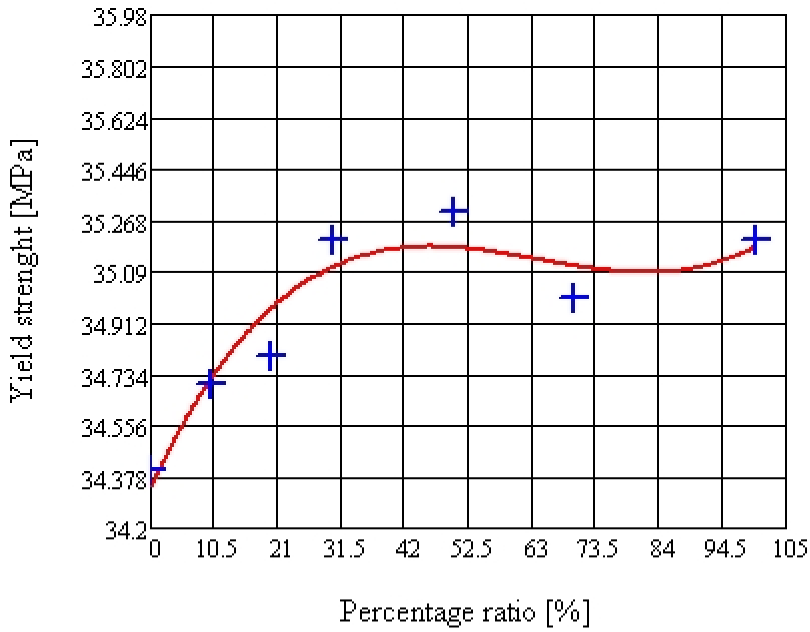

Figure. 4 Yield strength

$$YP = -32{,}17.10^{-4}.x^2 + 0{,}04426.x + 34{,}34$$

Where: YP - Yield Point

x - percentage of recycled granulate

Correlation index of measured (blue points) and calculated (red curve) values is 93,01 %, dispersion is 0,091 and standard deviation was calculated 0,306. Calculation was realized based on following assumptions and equations. Let X be a random variable, which takes the final or countless many values. Then we define dispersion as :

$$VAR[X] = \frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1} \text{ and deviation is } DEV[X] = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1}}$$

Measured values of yield stress and average values are shown in table 4.

Table. 4 Measured values of σy zaterial Mosten GB005

Sample	Number of material class – percentral ratio of recycled material						
	1 - 0%	**2 - 10%**	**3 - 20%**	**4 - 30%**	**5 - 50%**	**6 - 70%**	**7 -100%**
1	35,2	35,0	34,7	35,0	35,2	35,0	35,4
2	34,3	35,3	34,4	34,8	35,3	35,0	35,2
3	34,0	34,9	34,6	35,2	35,5	35,1	35,1
4	34,3	34,9	34,8	35,0	35,4	35,0	35,1
5	34,2	34,0	34,8	35,3	35,5	35,1	35,4
6	34,2	34,6	34,3	35,2	35,5	35,0	35,1
7	34,5	34,7	35,3	35,3	35,5	35,1	35,3
8	34,4	34,0	34,8	35,4	35,1	35,1	35,4
9	34,6	34,7	35,0	35,3	35,1	35,1	35,3
10	34,3	34,9	35,0	35,0	34,9	35,0	34,6
Average [MPa]	**34,4**	**34,7**	**34,8**	**35,2**	**35,3**	**35,0**	**35,2**

Graphical dependence on Figure 36 shows that with increasing ratio of regranulateis increasing yield strength. Pure material (class no. 1) containing no regranulate values σy stood at 34.4 MPa. Addition of the granulate of 10% (the material class no. 2) to 50% (the material class no. 5) to the base material, yield stress is raised progressively from 34.7 MPa to 35.3 MPa, which was the maximum measured value. Yield stress slight decrease was recorded in the material class no. 6, where the value decreased to 35.0 MPa. Increase of σyvalue was observed in the material class no. 7 and the value of 35.2 MPa.

Following figure (fig.5) represents dependence of nominal elongation on ratio of regranulate.

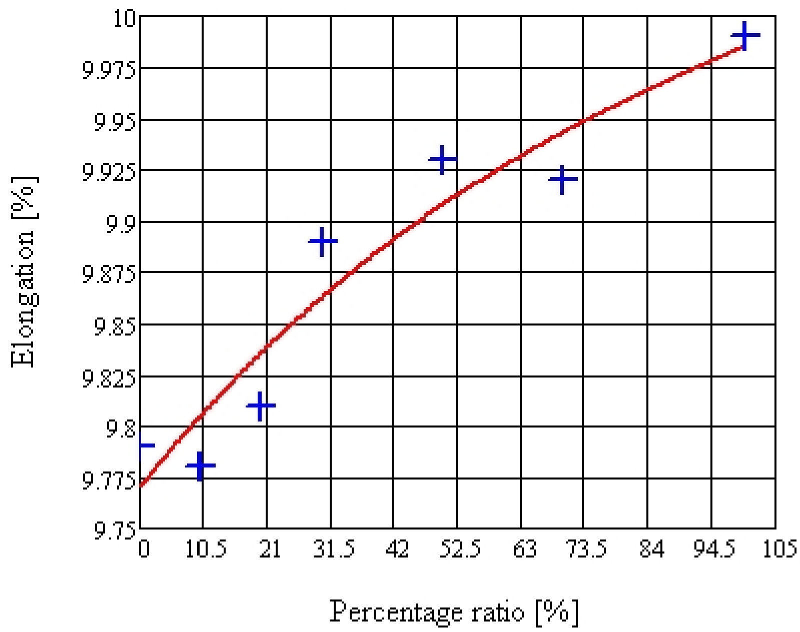

Figure. 5 Elongation before fraction

$$E = -2{,}7.10^{-5}.x^2 + 0{,}00237x + 9{,}77$$

Where: E - Elongation

x - percentage of recycled granulate

Correlation index of measured (blue points) and calculated (red curve) values is 95,3 %, dispersion is 0,00563 and standard deviation was calculated 0,075. Calculation was realized based on following assumptions and equations. Let X be a random variable, which takes the final or countless many values. Then we define dispersion as :

$$VAR[X] = \frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1} \text{ and deviation is } DEV[X] = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1}}$$

Measured and average values of nominal elongation are listed in table below (tab. 5)

Table. 5 Measured values of ε_t material Mosten GB005

Sample	**Number of material class – percentral ratio of recycled material**						
	1 - 0%	**2 - 10%**	**3 - 20%**	**4 - 30%**	**5 - 50%**	**6 - 70%**	**7 -100%**
1	10,00	9,82	9,93	10,00	9,90	10,29	9,41
2	10,10	9,68	9,61	9,31	9,44	9,80	9,44
3	9,51	9,56	9,61	9,61	9,56	9,91	9,44
4	9,41	9,34	9,80	10,39	9,90	9,88	10,78
5	10,39	9,68	9,61	9,56	10,00	9,91	9,85
6	9,56	9,56	9,61	10,29	9,61	9,81	10,00
7	9,71	10,15	10,05	9,90	10,47	9,80	9,49
8	10,05	9,62	10,05	9,31	9,41	10,14	9,80
9	9,80	9,80	9,68	10,20	10,78	9,84	11,40
10	9,41	10,59	10,12	10,29	10,20	9,85	10,25
Average [%]	**9,79**	**9,78**	**9,81**	**9,89**	**9,93**	**9,92**	**9,99**

The results of the measurements of the nominal elongation varied in the range of 9.78% for the pure material with 10% content of granulate (class no. 2) to 9.99%, for a material with 100% content of granulate (class no. 7). Material class no. 1 totaled at 9.79%. A decrease of 0.1% occurred in the material class no. 2 with 10% regrind to the base material. For materials class no. 3, 4 and 5 there was a gradual increase in values of 9.81% to 9.93%. A further decline of 0.1% was recorded in the material class no. 6 (70% granulate) to 9.92%. Increasing was achieved at 100% Plastic Raw (class no. 7), which represents the value of 9.99%.

Figure 6 shows graphical dependence of nominal elongation at fracture on ratio of regranulate.

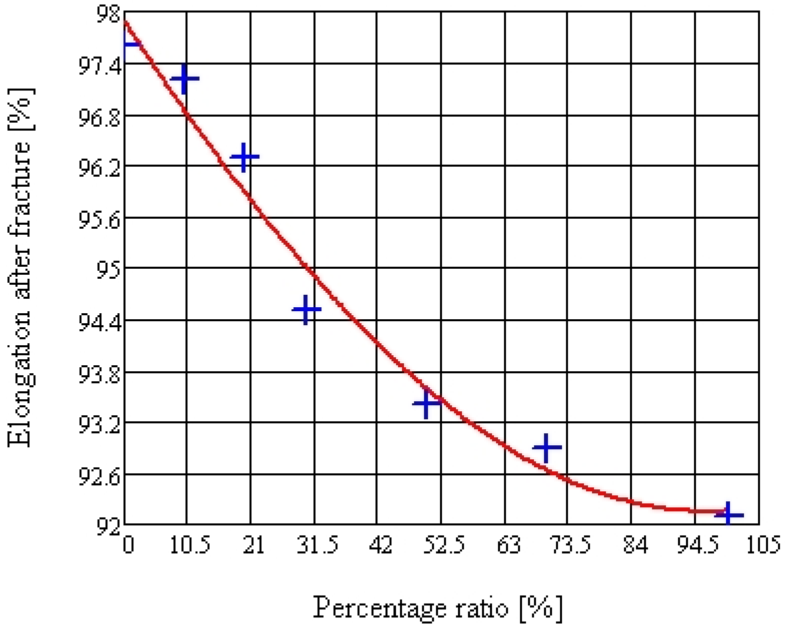

Figure. 6 Elongation after fracture depend on percentage ratio of recyclate

$$EF = 1{,}17.10^{-6}.x^3 + 3{,}96.10^{-4}.x^2 - 0{,}1.x + 97{,}88$$

Where: EF - Elongation after fracture

x - percentage of recycled granulate

Correlation index of measured (blue points) and calculated (red curve) values is 98,66 %, dispersion is 4,11 and standard deviation was calculated 2,028. Calculation was realized based on following assumptions and equations. Let X be a random variable, which takes the final or countless many values. Then we define dispersion as :

$$VAR[X] = \frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1} \text{ and deviation is } DEV[X] = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1}}$$

Measured and average values of nominal elongation at fracture are listed in table below (Tab. 6)

Table. 6 Measured values of ε_{tB} material Mosten GB005

Sample	**Number of material class – percentral ratio of recycled material**						
	1 - 0%	**2 - 10%**	**3 - 20%**	**4 - 30%**	**5 - 50%**	**6 - 70%**	**7 -100%**
1	85,3	92,7	106,7	98,1	86,5	98,5	91,0
2	82,0	90,7	96,4	96,6	99,5	84,1	98,0
3	94,0	117,2	109,3	92,3	104,3	81,3	96,6
4	124,7	92,9	87,0	88,7	80,8	109,8	97,7
5	88,2	105,7	79,7	103,7	89,7	105,3	85,4
6	107,8	100,4	95,9	87,5	91,5	79,5	92,7
7	96,1	101,6	105,9	95,0	85,0	80,6	73,5
8	105,8	84,0	106,3	96,9	85,5	79,4	101,0
9	100,7	107,6	99,5	89,5	107,7	97,8	97,6
10	91,4	79,0	76,9	96,5	103,5	112,5	77,5
Average [%]	**97,6**	**97,2**	**96,3**	**94,5**	**93,4**	**92,9**	**92,1**

Graphical dependence (Figure 6) shows that maximum value of the nominal elongation at fracture 97.6% reached the class material no. 1 (pure material). Increase of the ratio of regranulate material causes decrease to value 97.2% in the material class no. 2 (10% regrind) to 92.1% in the material class no. 7 (100% regranulate), as the lowest measured value.
Following figure (fig 7) shows dependence of tensile strength at fracture on percental ratio of regranulate.

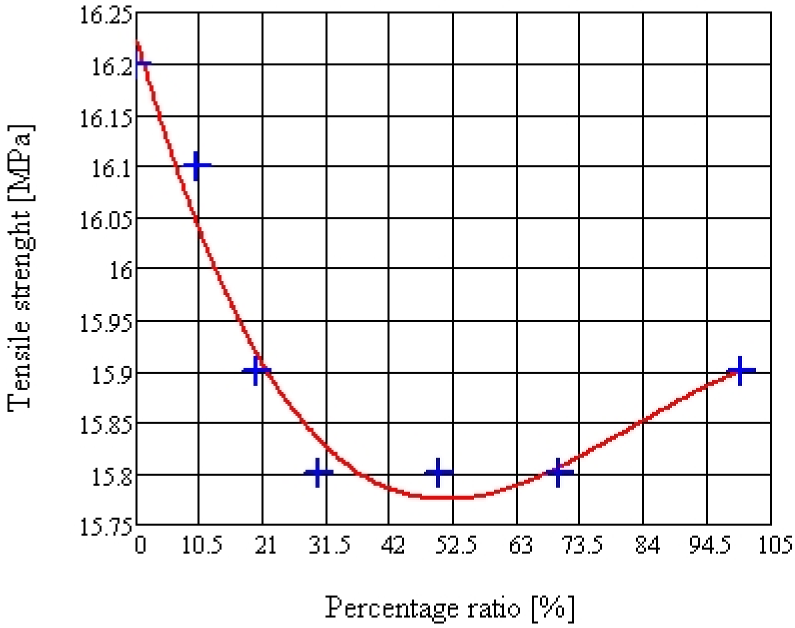

Figure. 7 Dependence of tensile strength on various percentage ratio of recyclate

$$T = -1{,}2.10^{-6}.x^3 + 2{,}96.10^{-4}.x^2 - 0{,}021.x + 16{,}22$$

Where: T - Tensile strength
x - percentage of recycled granulate

Correlation index of measured (blue points) and calculated (red curve) values is 98,39 %, dispersion is 0,022 and standard deviation was calculated 0,149. Calculation was realized based on following assumptions and equations. Let X be a random variable, which takes the final or countless many values. Then we define dispersion as :

$$VAR[X] = \frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1} \text{ and deviation is } DEV[X] = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1}}$$

Measured and average values of tensile strength at fracture are listed in table below (tab.7)
Table. 7 Measured values of σB material Mosten GB005

Sample	Number of material class – percentral ratio of recycled material						
	1 - 0%	**2 - 10%**	**3 - 20%**	**4 - 30%**	**5 - 50%**	**6 - 70%**	**7 -100%**
1	14,60	15,70	15,11	15,04	15,04	16,35	15,04
2	17,66	17,10	15,70	16,31	14,95	15,49	16,88
3	16,95	17,10	15,98	16,61	15,64	15,75	17,63
4	16,39	17,02	14,81	16,49	16,35	15,30	16,16
5	17,29	17,48	16,05	15,45	14,96	16,17	16,65
6	16,88	15,02	14,96	14,82	16,01	16,84	14,40
7	14,45	16,76	16,99	14,73	15,26	16,59	9,60
8	14,14	15,49	15,90	16,05	15,11	14,69	15,30
9	17,14	13,95	17,10	16,80	17,17	14,66	16,91

10	16,73	15,11	16,46	15,98	17,59	16,73	20,17
Average [MPa]	**16,2**	**16,1**	**15,9**	**15,8**	**15,8**	**15,8**	**15,9**

In dependence on measurement results (fig 39)can be stated that the maximum value (16.2 MPa) was measured in material class no. 1 and minimum (15.8 MPa) for a material class no. 4, 5 and 6. With higher ratio of regranulate material was observed decrease in the value for a material batch no. 2 to 5. For materials with 70% and a 100% regranulate increased slightly to 15.8 in the material class no. 6 and to 15.9 for the material class no. 7th

Hardness test was performed using hardness tester Instron 902B with a digital display for hardness readings. The test was performed in accordance with standard EN ISO 868.

Next picture (Fig. 8) shows graphical dependence of hardness on precentral ratio of regranulate.

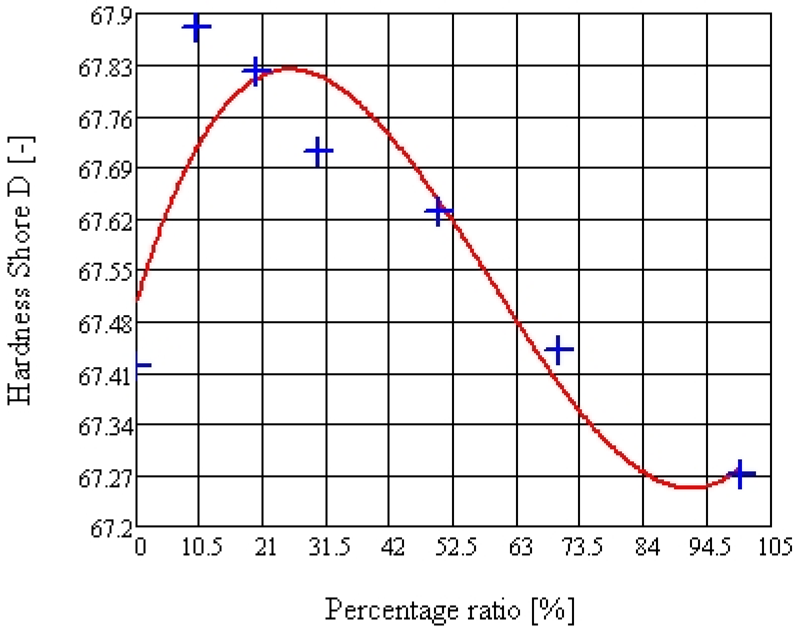

Figure. 8 Dependence of measured and calculated values of hardness Shore D on volume of recyclate for material MOSTEN

$$HS = 3{,}93.10^{-6}.x^3 - 6{,}897.10^{-4}.x^2 + 0{,}0276.x + 67{,}5$$

Where: HS - Hardness Shore D

x - percentage of recycled granulate

Correlation index of measured (blue points) and calculated (red curve) values is 92,39 %, dispersion is 0,0438 and standard deviation was calculated 0,209. Calculation was realized based on following assumptions and equations. Let X be a random variable, which takes the final or countless many values. Then we define dispersion as :

$$VAR[X] = \frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1} \text{ and deviation is } DEV[X] = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1}}$$

Measured and average values of Shore hardness are listed in following table (tab. 8.)

Table. 8 Measured values of hardness for material MOSTEN GB005

Sample	**Number of material class – percentral ratio of recycled material**						
	1 - 0%	**2 - 10%**	**3 - 20%**	**4 - 30%**	**5 - 50%**	**6 - 70%**	**7 -100%**
1	67,50	68,10	68,40	67,40	67,60	67,30	67,10
2	67,20	68,30	68,60	67,40	67,60	67,10	67,30
3	67,00	68,10	68,50	67,40	67,60	67,40	65,20

4	67,30	68,40	67,70	68,40	67,80	67,60	67,00
5	67,40	68,30	67,70	67,60	67,30	67,70	66,60
6	67,30	68,00	68,10	67,90	67,50	66,90	67,90
7	67,80	67,30	68,30	68,00	67,80	67,20	67,80
8	67,60	67,30	67,90	67,20	67,80	67,70	67,60
9	67,40	67,80	66,80	67,80	67,60	67,70	67,90
10	67,70	67,20	66,20	68,00	67,70	67,80	68,30
Average Shore D	**67,42**	**67,88**	**67,82**	**67,71**	**67,63**	**67,44**	**67,27**

Shore D hardness of the material Mosten GB005 material class no. 1 reaches average value of the Shore D 67.42. At the ratio of 10% reregranulate into the base material (class no. 2) was increase of hardness of Shore D 67.88. For material classes no. 3-7 was observed that increasing the ratio of the regranulate leads to decrease in the average values of hardness from value of 67.82, for a material with a regranulate ratio 20% (class no. 3) to value D 67.27 100% at regranulate.

For evaluation of impact strength was used impact hammer CEAST Resil 5.5 and software WINMFT. The test was performed in accordance with standard EN ISO 179-1: 2010.

Testing methods:

- ISO 179-1/1eU –impact strength
- ISO 179-1/1eA –notch toughness

Experimental conditions (ISO 179-1/1eU):

- Impact velocity – 2,9 m/s ± 10%
- Nominal energy of pendulum – 5 J
- Temperature of test sample
- Type of fracture – C –full fracture

Table 9 shows measured values of impact strength for temperature 23 °C and nominal energy of pendulum 5J.

Table. 9 Measured values of impact strength material Mosten GB005

vzorka	**Number of material class – percental ratio of recycled material a_{cU} [kj/m^2]**						
	1 - 0%	**2 - 10%**	**3 - 20%**	**4 - 30%**	**5 - 50%**	**6 - 70%**	**7 -100%**
1 - 10	**WITHOUT FINAL FRACTURE**						

Based on the test results of impact strength test can be stated that under the current conditions of test material for classes 1-7 at 23 ° C no fracture occurs.

Following figure 9 shows values impact strength at -30 ° C for measurements of individual classes with varying ratio of regranulate.

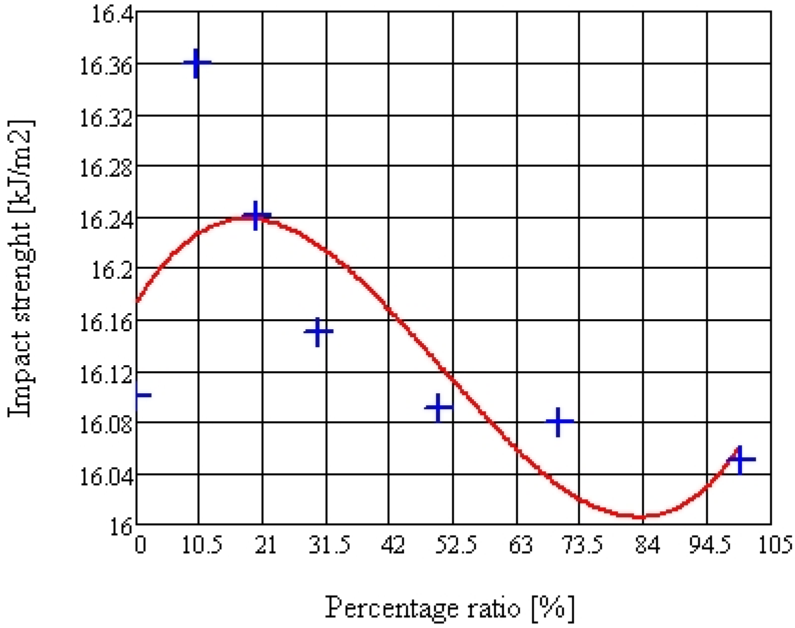

Figure. 9 Graphical dependence of impact strength on volume of recyclate

$$IS = 1{,}704.10^{-6}.x^3 - 2{,}598.10^{-4}.x^2 + 16{,}172$$

Where: IS - Impact strength

x - percentage of recycled granulate

Correlation index of measured (blue points) and calculated (red curve) values is 75,23 %, dispersion is 0,01313 and standard deviation was calculated 0,102. Calculation was realized based on following assumptions and equations. Let X be a random variable, which takes the final or countless many values. Then we define dispersion as :

$$VAR[X] = \frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1} \text{ and deviation is } DEV[X] = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1}}$$

Measured and average values of impact strength at -30°C are listed in table 10.

Table. 10 Measured values of impact strength for material Mosten GB005 at temperature -30oC

Sample	**Number of material class – percentral ratio of recycled material a_{cU}**						
	1 - 0%	**2 - 10%**	**3 - 20%**	**4 - 30%**	**5 - 50%**	**6 - 70%**	**7 -100%**
1	16,025	16,300	16,825	15,850	16,175	15,875	15,725
2	15,975	16,150	16,075	15,725	15,775	16,450	16,350
3	16,225	16,300	16,175	16,075	16,175	15,725	16,075
4	17,150	16,525	16,250	16,600	15,550	16,250	16,175
5	15,950	16,200	16,075	16,350	16,075	16,600	16,250
6	15,725	16,150	16,175	16,000	16,175	16,450	15,875
7	16,550	16,525	15,825	16,075	16,050	15,975	16,350
8	16,075	16,300	16,250	16,600	16,175	15,975	15,975
9	15,600	16,450	16,550	16,175	16,550	15,875	15,875
10	15,725	16,650	16,175	16,075	16,175	15,625	16,075
Average [kj/m²]	**16,10**	**16,36**	**16,24**	**16,15**	**16,09**	**16,08**	**16,07**
Fracture type	*C*	*C*	*C*	*C*	*C*	*C*	*C*

Results of impact strength tests shown in Figure 9, that maximal value16.36 kJ.m-2 was reached in sample class no.2 with 10% content of regranulate. With further increase of regranulate ratio in base material was observed decreasing of the values from 16.36 kJ.m-2 for the material class no. 2 to minimum 16.07 m-2 for the material class no. 7th

Determining notch toughness was realized according to standard ISO 179-1/1eA and was set following conditions:

- impact velocity – 2,9 m/s ± 10%
- nominal energy of the pendulum – 0,5 J
- temperature of testing sample – 23oC / -30oC
- fracture type – C – complete fracture (see table)

Values of notch toughness at temperature 23°C are shown in figure 10 as dependence on percentage ratio of recycled material.

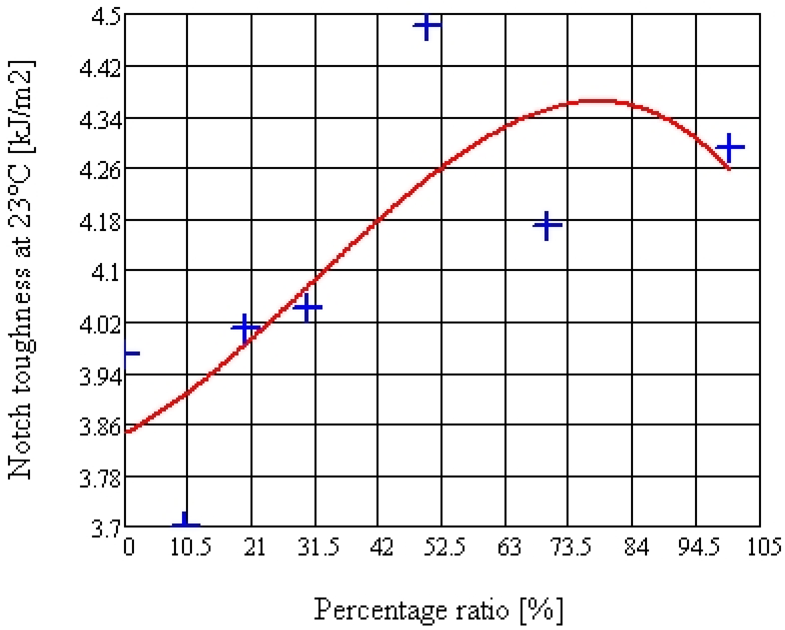

Figure. 10 Graphical dependence of notch toughness at temperature 23°C for various percentage ratio of recycled granulate

$$NT = -1{,}36.10^{-6}.x^3 + 1{,}28.10^{-4}.x^2 + 3{,}85$$

Where: NT - Notch toughness

x - percentage of recycled granulate

Correlation index of measured (blue points) and calculated (red curve) values is 77,03 %, dispersion is 0,0533 and standard deviation was calculated 0,2311. Calculation was realized based on following assumptions and equations. Let X be a random variable, which takes the final or countless many values. Then we define dispersion as :

$$VAR[X] = \frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1} \text{ and deviation is } DEV[X] = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1}}$$

Results of notch toughness as dependence on percentage ratio of recyclate are in table 11 at temperature 23°C.

Table. 11 Measured values of notch toughness for material Mosten GB005 at temperature 23oC

Sample	Number of material class – percentral ratio of recycled material a_{cN}						
	1 - 0%	**2 - 10%**	**3 - 20%**	**4 - 30%**	**5 - 50%**	**6 - 70%**	**7 -100%**
1	3,969	4,094	4,219	4,094	4,563	4,313	4,406
2	3,969	3,500	4,063	4,063	4,313	4,031	4,188
3	3,719	3,281	4,344	4,031	4,469	4,156	4,281
4	4,125	4,156	4,063	4,219	4,563	4,094	4,281
5	3,969	3,094	3,219	3,438	4,688	4,375	4,250
6	4,094	3,750	3,844	4,500	5,281	4,344	4,031
7	3,969	3,813	4,000	3,594	4,250	4,125	4,375
8	4,188	3,813	4,094	4,188	4,313	3,938	4,281
9	3,875	3,719	4,063	4,094	4,063	3,906	4,500
10	3,781	3,813	4,219	4,219	4,250	4,438	4,188
Priemer [kj/m²]	**3,97**	**3,70**	**4,01**	**4,04**	**4,48**	**4,17**	**4,28**
Fracture type	*C*	*C*	*C*	*C*	*C*	*C*	*C*

The graph in Figure 10 describes the impact of recyclate on notch toughness and values are in range from 3.70 to 4.48 kJ.m-2. The minimum value was recorded in the material class no. 2 (10% recyclate) 3.70 kJ.m-2. Material class no. 3 and 4 were approximately the same value of the notch toughness in comparison with material class no. 1 4.0 kJ.m-2. At 50% strength relative to the base granulate material impact toughness ACN reached a maximum value of 4,48 kJ.m-2. Materials classes no. 6 and 7 are characterized by decrease of the decrease of the maximum values, where the 70% recyclate content in the base material granulate was 4.17 kJ.m-2, and at 100% was measured value 4.28 kJ.m-2.

Values of notch toughness at temperature -30°C are shown in figure 11 as dependence on percentage ratio of recycled material.

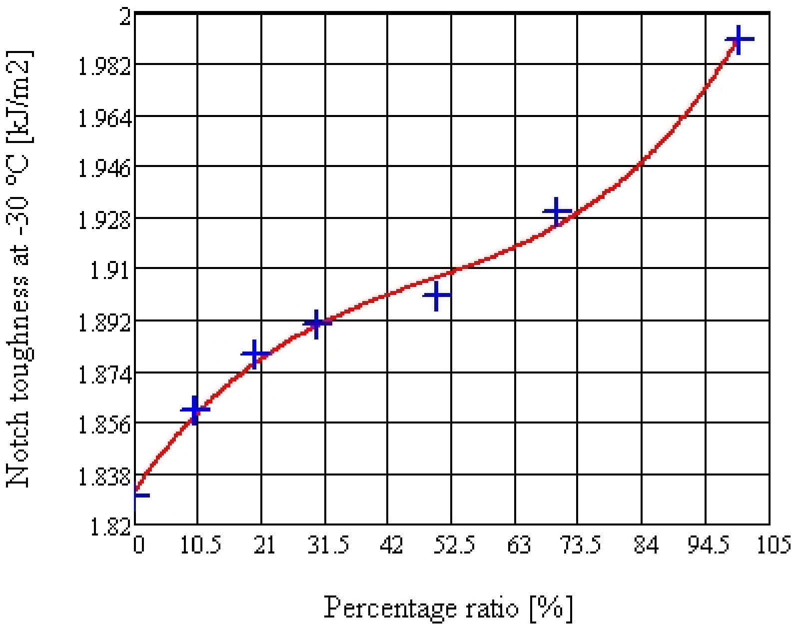

Figure. 11 Graphical dependence of notch toughness at temperature -30°C for various percentage ratio of recycled granulate

$$NTC = 0{,}0031.x2 + 1{,}83293$$

Where: NTC - Notch toughness -30°C

x - percentage of recycled granulate

Correlation index of measured (blue points) and calculated (red curve) values is 99,75 %, dispersion is 0,0023 and standard deviation was calculated 0,0477. Calculation was realized based on following assumptions and equations. Let X be a random variable, which takes the final or countless many values. Then we define dispersion as :

$$VAR[X] = \frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1} \text{ and deviation is } DEV[X] = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1}}$$

Results of notch toughness at temperature -30°C for various percentage ratio are shown in table 12.

Table. 12 Measured values of notch toughness for material Mosten GB005 at temperature -30oC

sample	**Number of material class – percentral ratio of recycled materiala$_{cN}$**						
	1 - 0%	**2 - 10%**	**3 - 20%**	**4 - 30%**	**5 - 50%**	**6 - 70%**	**7 -100%**
1	1,813	1,416	1,750	1,844	2,000	1,844	2,031
2	1,750	1,813	2,219	1,844	1,813	2,094	1,750
3	1,781	1,875	2,344	1,938	2,219	2,063	2,219
4	2,125	1,750	1,875	1,813	2,219	2,094	1,938
5	1,781	2,031	1,688	1,844	1,750	2,000	2,375
6	1,750	2,188	1,969	1,813	1,781	1,750	1,625
7	1,875	2,156	1,875	1,813	1,719	1,781	1,813
8	1,813	2,094	1,719	1,938	2,063	1,813	1,969
9	1,813	1,438	1,656	2,031	1,719	2,125	2,000
10	1,781	1,813	1,688	2,016	1,719	1,719	1,781
Average [kj/m^2]	**1,83**	**1,86**	**1,88**	**1,89**	**1,90**	**1,93**	**1,95**
Fracture type	*C*	*C*	*C*	*C*	*C*	*C*	*C*

Testing the notch toughness of the material Mosten at temperature -30 ° C was monitored impact of recyclate percentage on the values of notch toughness. Increasing the recycle granulate causes increasing of the notch toughness from 1.83 kJ.m-2, for a material class no. 1 (0% regrind) to 1.95 kJ.m-2 with a clear granulates.

Evaluating the flexure modulus was realized by using tensile machine Hounsfield H10 KT with software Qmat according to standard ISO EN 178:2003.

Evaluated parameters:

- flexural modulus Ef (MPa) - the ratio of a differential stress σf2 - σf1 to the value corresponding to the difference deformation εf2 (0.0005) - εf1 (0.0025
- σfM flexural strength (MPa) - the highest value of the bending stress.

Conditions of testing for all experimental samples:

- overload – 2 N
- feed rate – 2 mm/min
- distance between supports – 64 mm
- scanning heas – 500 N

Mosten thermoplastic granules were not necessary according to the material sheet before the injection specially treated.

Graphical dependences of flexural modulus on percentage of recycled material is shown in figure 12.

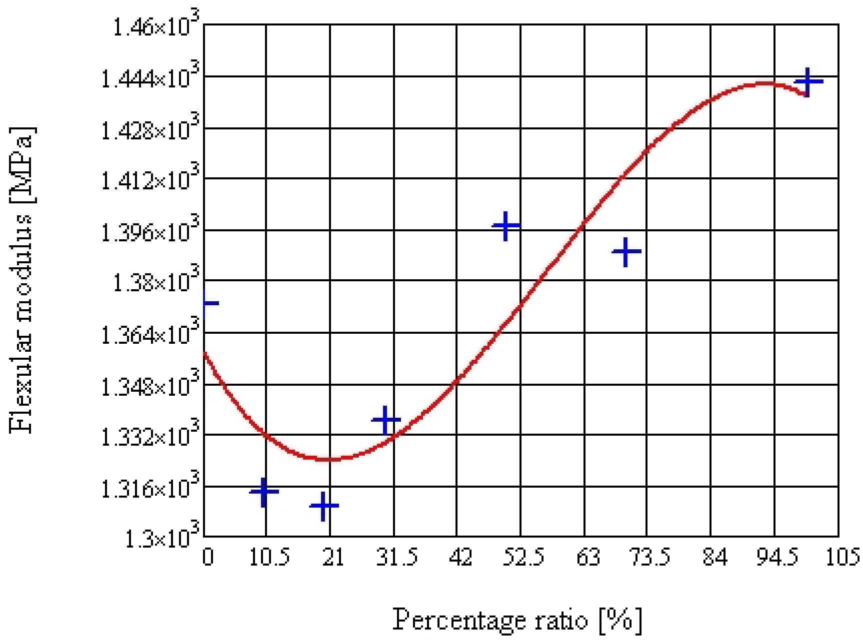

Figure. 12 Flexural modulus test for material Mosten for various recycle percentage of granulate

$$FM = -6{,}2387.10^{-4}.x^3 + 0{,}106.x^2 - 3{,}566.x + 1357{,}61$$

Where: FM - Flexural modulus

x - percentage of recycled granulate

Correlation index of measured (blue points) and calculated (red curve) values is 91,25 %, dispersion is 2010,67 and standard deviation was calculated 44,84. Calculation was realized based on following assumptions and equations. Let X be a random variable, which takes the final or countless many values. Then we define dispersion as :

$$VAR[X] = \frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1} \text{ and deviation is } DEV[X] = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1}}$$

Results from flexural modulus testing are shown in table 13.

Table. 13 Average values of Efof testing experimental material Mosten GB 005

sample	**Number of material class – percentral ratio of recycled material**						
	1 - 0%	**2 - 10%**	**3 - 20%**	**4 - 30%**	**5 - 50%**	**6 - 70%**	**7 -100%**
1	1530,0	1305,0	1350,0	1350,0	1410,0	1390,0	1485,0
2	1417,5	1305,0	1305,0	1327,5	1350,0	1395,0	1417,5
3	1327,5	1305,0	1282,5	1305,0	1395,0	1382,5	1417,5
4	1282,5	1350,0	1282,5	1350,0	1412,5	1395,0	1462,5
5	1305,0	1305,0	1327,5	1350,0	1417,5	1382,5	1417,5
Average [MPa]	***1372,5***	***1314,0***	***1309,5***	***1336,5***	***1397,0***	***1389,0***	***1440,0***

The average values of the flexural modulus Ef are shown in the graph in Figure 66. The values are in the range from 1309.5 MPa at material class no. 3 to 1440.0 MPa of material class no. 7. Material class no. 1 reached an average value of 1372.5 MPa. For materials class no. 2 and 3, the average value decrease to the level of 1314.0 MPa, for material class no. 2 and on the value 1309.5 MPa for the material class no. 3. Further increases of the percentage ratio of recycling granulate to the base material cause gradual increase in the values of the flexural modulus Ef, for a material class no. 4 and 5. The slight decrease occurred in the material with 70% recyclate to the average value 1389.0 MPa and at 100% recyclate ratio was value was measured the highest value of the flexural modulus Ef.

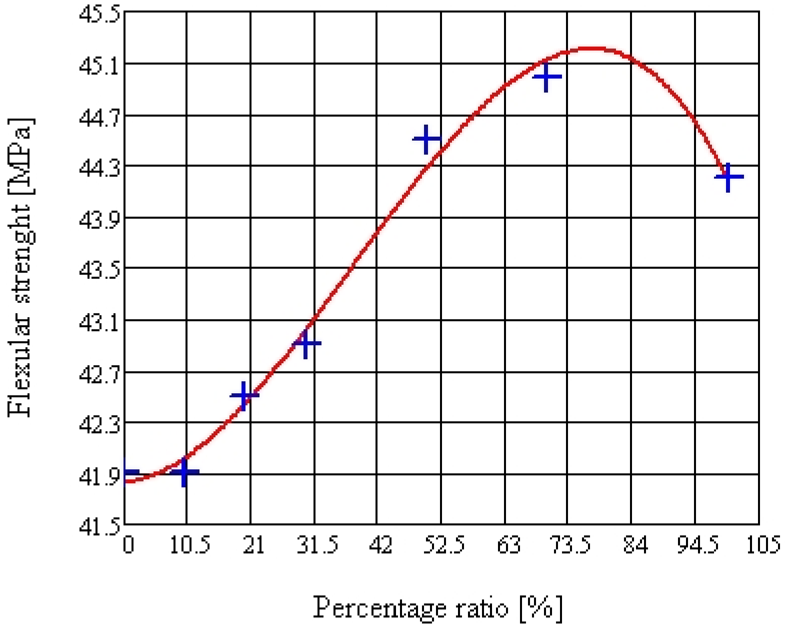

Figure. 13 Flexural strength of the material MOSTEN for various material classes

$$FS = -1,3999.10^{-4}.x^3 + 0,0016.x^2 + 0,00426.x + 41,82$$

Where: FS - Flexural strength
x - percentage of recycled granulate

Correlation index of measured (blue points) and calculated (red curve) values is 99,79 %, dispersion is 1,39 and standard deviation was calculated 1,18. Calculation was realized based on following assumptions and equations. Let X be a random variable, which takes the final or countless many values. Then we define dispersion as :

$$VAR[X] = \frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1} \text{ and deviation is } DEV[X] = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x)^2}{n-1}}$$

Average values of experimental result of the flexural strength tests are shown in table 14.

Table. 14 Average values of the σfMfor material Mosten GB 005

SAMPLE	**Number of material class – percentral ratio of recycled material**						
	1 - 0%	**2 - 10%**	**3 - 20%**	**4 - 30%**	**5 - 50%**	**6 - 70%**	**7 -100%**
1	42,2	41,9	42,5	42,6	44,5	44,9	44,3
2	42,1	41,7	42,6	42,8	43,5	44,6	44,3
3	42,1	41,8	42,3	43,0	44,5	44,2	44,4
4	41,9	42,2	42,6	42,9	44,7	44,2	44,2
5	41,5	42,1	42,4	42,7	44,5	44,6	44,4
Average [MPa]	***41,9***	***41,9***	***42,5***	***42,8***	***44,3***	***44,5***	***44,3***

The graphical dependence shown in Figure 13 the average value of the flexural strength test σfM were in the range from 41.9 MPa for the material class no. 1 and 2 (10% and 20% recyclate) to 44.5 MPa at the material class no. 6 (70% recyclate). Increasing the percentage ratio of the recyclate granulate cause also increase of values σfM where in the material classes no. 3 and 4 were measured by an average values 42.5 MPa and 42.8 MPa. The most significant increase in the values of flexural σfM was monitored in the material class no. 5 (50% recyclate), where the average value was around 44.3 MPa. The maximum value was measured at 70% recyclate added into the base material. At 100% recyclate material the value of σfM decreased by 0.2 MPa compared to the maximum to 44.3 MPa.

Method DSC (Differential Scanning Calorimetry) is aimed for monitoring transition temperatures of polymers to detect temperatures of glass transition, crystal melting and crystallization to fast identification of unknown polymer material and also to quality assessment of the testing parts by degree of the crystallinity(melting enthalpy auxiliary), to evaluation the cinematic of crystallization, to evaluation copolymers and polymer mixtures, to study of a steady state, changes and to evaluate the degradation. Measuring was realized according to standard EN ISO 11357-1:2010.

Experimental research was focused on evaluation of calorimetric curves for the material MOSTEN GB005 with the recycle ratio 0%, 50% and 100% to prescribe the effect of the recycle material on process of melting, solidification and crystallization.

Microstructures of testing material show significant impact of recyclate on gains, where with the increasing recyclate ratio is microstructures is finer (Fig. 14).

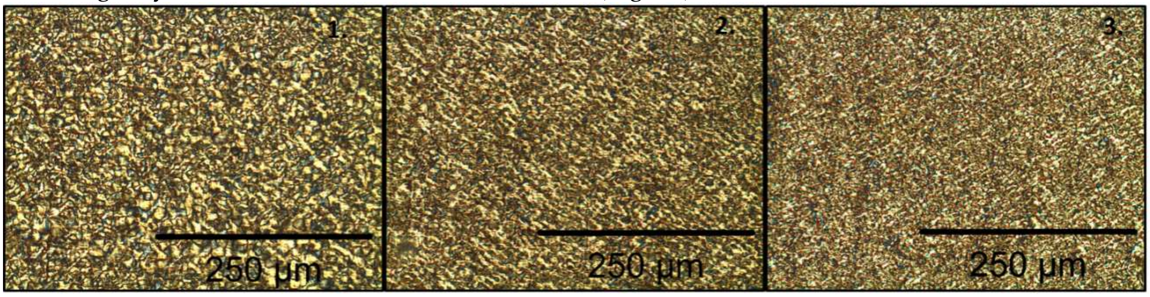

Figure. 14 Microstructure of material MOSTEN GB005 (1. 0%-recyclate, 2. 50% recyclate, 3. 100% recyclate)

Graphical dependences shown in figure …. Represent calorimetric curves for different recyclate ratio (0%, 50% and 100%). Curves provide information about recyclate impact on calorimetric properties and can be state, that ratio of recyclate do not significantly affect calorimetric curves and material´s endothermic and exothermic reaction (Fig. 15).

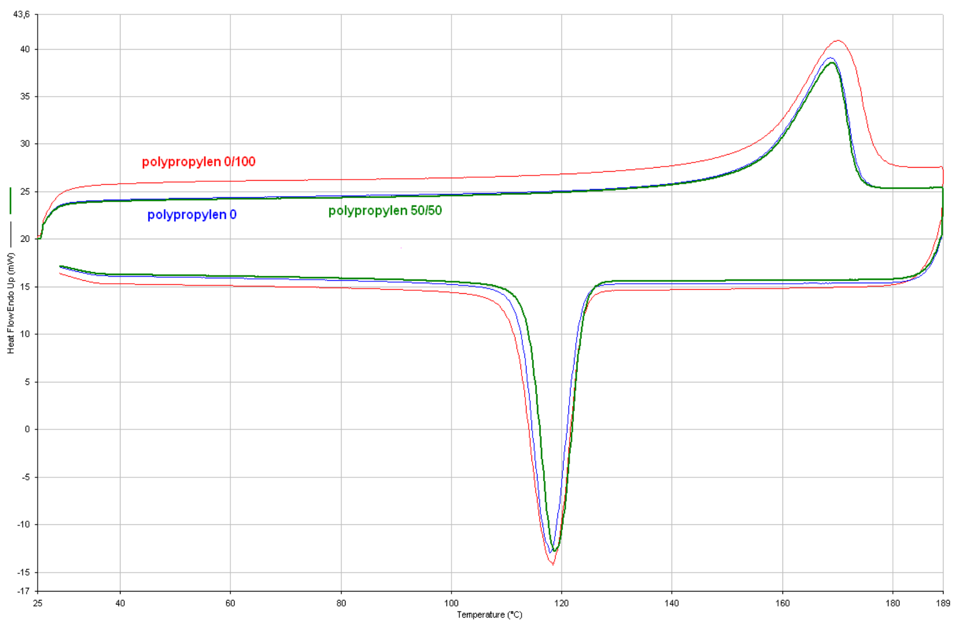

Figure.15 Calorimetric curves

Ratio of recyclate 0% and 50% represent almost ideal and identical curves of calorimetry, but at 100% ratio of recyclate is seen increase of heat flow, although initial and final temperatures for exothermic and endothermic reaction are in range from 2 ° C. Percentage of the recyclate ratio causes increase of initial melting temperature from 134,676°C at 0% to 139,715°C at 100% ratio of the recyclate. Melting enthalpy was measured at 0°C with value of enthalpy -122,941J/g, at 50% was measured value -114,78 J/g and at 100% was value -135,778 J/g. In the fact of this can be state the result that the smallest amount of the heat supplied to change physical state was detected at recyclate ratio 50% and also similar occasion occurred at enthalpy (heat transferred during solidification).

5. Conclusions

Paper was focused on evaluation of mechanical, rheological and calorimetric properties of material MOSTEN GB 005. Subsequently was analyzed impact of percentual ratio of recycled material on material properties. The analysis was performed on test samples made according to the relevant standards. Samples were tested on tensile and flexural properties and also test the hardness and impact strength Charpy. Rheological properties were tested to analyze the test rod volume flow. The purpose of these tests was to find that the ratio of regrind to the base material, that would not maintain the required mechanical properties and quality products.

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Author Contributions: Jozef Zajac conceived and designed the experiments, Dusan Mital and Zuzana Hutyrova analyzed and evaluated data, Frantisek Botko and Michal Hatala processed data and wrote the paper, Jozef Dobransky and Lubos Behalek performed the experiments and measurements

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