Heat Treatment by Applying Tempering at Low Temperature of WNR. 1.2083 Steel, Used in the Injection Molding of PBT Reinforced with up to 45% Fiberglass

ALEXANDRU BRAN*, NICOLAE CONSTANTIN*
University Politehnica of Bucharest, 313 Splaiul Independentei, 060042, Bucharest, Romania

This paper had as special-purpose rendering the enhancing of WNR. 1.2083 steel's properties by vacuum heat treatment, in protective atmosphere, in order to find adequate solutions for the improvement of the tools destined for the injection molding of PBT reinforced with up to 45% fiberglass, for the total cost of a mold production project divided per the total number of the resulted pieces from that project to reach its minimum value. For that purpose to be achieved, the use of high performance steels with special alloying concept and distinct production technique is mandatory. Although the electroslag remelting process ensures a smaller number of non-metallic inclusions and a homogenous structure characterized by isotropic properties, this has to be extended after heat treatment also. By identifying the problems involved in the injection process PBT reinforced with up to 45% fiberglass, the right characteristics of the WNR. 1.2083 steel were established. In order for those characteristics to be reached, the execution of the proper heat treatment in vacuum furnaces, with protected atmosphere, will be presented in this paper.

Keywords: reinforced PBT, fiberglass, heat treatment, vacuum, low tempering, distortion

The usage of plastic had a huge growth over the last years and it became vital part of our everyday lives. Automotive components [1], electrical and electronically parts, food industry materials, packaging and products and many others are molded from plastic. The molds should be made out of materials with unique and demanding characteristics due to the strictness of the formed plastic by number, image and shape. For each mold it is mandatory to select the correct steel grade adequate to the process specifications. The steel is subjected to considerable stress by harsh working environment and, after identifying the problems involved in the process, the right chemical composition and elaboration method, added to the perfect hardness obtained by adequate heat treatment, should be carefully selected [2] together with objective quality optimized system for injection molding process parameters [3].

Excessive mold maintenance involves costs by major cleaning, replanting, repolishing and replacing of worn or broken parts. Also there are major concerns regarding the costs of production and down time, late-delivery penalties, overtime payment, and loss of customer because of the mold exploitation flaws.

Composite plastics include those sorts of plastics that represent the effect from mixing two or more homogeneous materials, with different material properties, in order to derive a final product with certain desired qualities and mechanical properties.

Fiber-reinforced plastics refer to a specific class of composite plastics that certainly use fiber materials to augment the strength and elasticity of plastics by mechanical means. The matrix represents a term for the original plastic material without fiber reinforcement. Because the matrix is usually a relatively weak plastic, it needs to be reinforced by adding stronger and stiffer reinforcing filaments or fibers. Fiberglass can be defined as a versatile material which combines light weight with very good strength in order to provide a weather resistant finish, with numerous surface textures. Textile glass fibers represent possible combinations of aluminum (III) oxide silicon dioxide, calcium oxide, boron trioxide or magnesium oxide in powder form. The filaments diameter and the number of filaments in the roving determine the weight of the fiberglass. It is a lightweight, robust and extremely strong material. Combining advanced strength with low weight represents a better alternative to metals in many applications.

In the injection molding process, the fiber-reinforced plastic is introduced into a heated cylinder. There the melt is pressed into the mold by the use of a rotating screw system or by hydraulic plunger. After the mold shape is fully and uniformly filled with melted plastic, it is cooled and ejected using ejectors. Impact resistance, scaling, erosion, corrosion resistance are some of the performance requirements that are mandatory in today's applications for plastic components. Besides crystallization [4] and orientation of polymers, the properties of the injected pieces are seriously influenced by flow ability, water absorption (0.3 % at 23 °C according to ISO 62) and shrinkage [5, 6].

Experimental part

Heat treatment of WNR. 1.2083 steel using tempering at low temperature

The mold contained two inserts of 100 x 250 x 300 mm made out of WNR. 1.2083 steel (the electroslag remelted version with superior homogeneity and better toughness than conventional melting type [7]). The holder plates were recommended to be made out of WNR. 1.2085 and the clamping plates out of WNR 1.2312.

Injection molding of PBT with 45 % fiberglass represents a problem for the final user of the tool. Because of the highly corrosive and highly abrasive processes that occur

* email: bran_n_alexandru@yahoo.ro; nctin2014@yahoo.com,

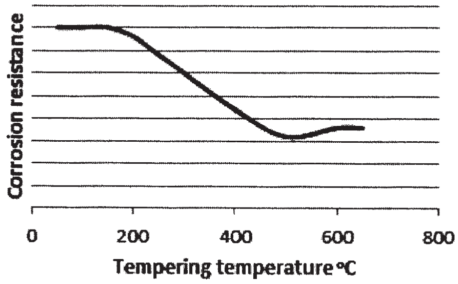

Fig. 1. Corrosion resistance related to tempering temperature of WNR. 1.2083 ESR steel

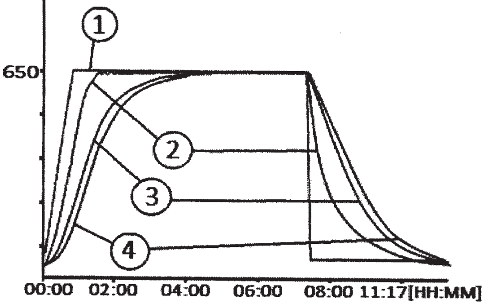

Fig. 2. The stress relieving process diagram: 1- programmed process temperature [°C], 2- ambience thermocouple temperature [°C], 3- temperature of the thermocouple located at approx. 1/4 the thickness of the workpiece [°C], 4 – temperature of the thermocouple located at approx. 1/2 the thickness of the workpiece [°C].

during the injection of the fiberglass reinforced PBT, the tool's life is drastically shortened [8, 9].

PBT is defined as semi-crystalline polyester which is resistant to solvents. PBT represents a structural engineering polymer that resists to temperatures up to 150 °C and it is mechanically strong. During forming, its dimensions are reduced insignificantly. It is a hard and though material with water adsorption, it presents good chemical resistance and electrical properties and it shows very good resistance to dynamic stresses [10]. The injected fiberglass reinforced PBT compound was chosen as Vestodur® X7212 NF + 45% GF type (Resin: ISO 7792-PBT [11], MFHR, A10-14, GF45; UL recognition: UL 94: V-0, all colors, UL 746B: RTI=140/140/140°C). The embedded flame retardant is defined as non-migrating [12]. With a density at 23°C of 1.84 g/cm^3 the injected material presents according to ISO 1133 a melt volume flow rate of 6 cm^3 / 10 min at 250 °C/2.16 kg, related to moisture content smaller than 0.05% [6]. The processing parameters [13] involve the temperature range of the injected material was around 230-260°C at a mold temperature range of 40-55°C, under a maximum injection pressure of 150 MPa.

The friction and wear processes are interdependent with the normal load or with the maximum pressure in the contact between the PBT and the steel [14] [15] [16] and they generate abrasive wear problems. By reinforcing with 45% fiberglass, the wear is exponentially increased and by the nature of the injection regime which involves high injection speeds, therefore the phenomenon is taken to its peak [13]. In order to avoid extreme material loss, the hardness of the mold should be high. Nevertheless the toughness, the thermal conductivity and, of course, the corrosion resistance must be carefully balanced, due to the water absorption characteristics involved by using this PBT.

The properties that the steel should fulfill after the heat treatment process are determined by the answer to what phenomenon the mold must resist. By the principles of increasing the productivity there should be achieved the

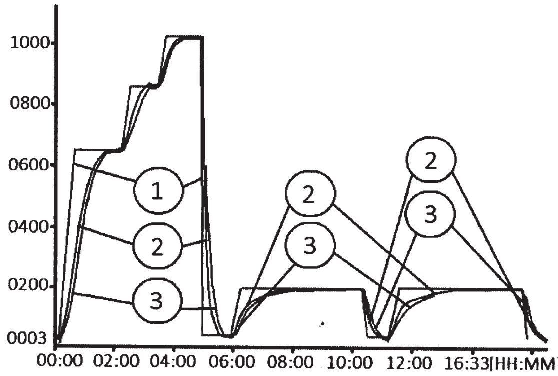

Fig. 3. The heating-quenching and tempering process diagram: 1- programmed process temperature [°C], 2- ambience thermocouple temperature [°C], 3 – temperature of the thermocouple located at approx. 1/2 the thickness of the workpiece [°C]

following criteria related to heat treatment quality: a shorter cycling time - the thermal conductivity of the mold must be high, lowest number of production interruptions - high toughness and hardness corroborated to corrosion resistance, maintenance - corrosion resistance. In order to achieve a longer tool life, the heat treatment must provide: high hardness and high compressive strength for abrasive wear and flash, high hardness and a substrate for future surface treatment for adhesive wear or galling, high compressive hardness/strength and corrosion resistance for a high surface quality. In the same time the quality of the injected piece is very important and, for that purpose to be reached, the following aspects must be provides by heat treatment: good thermal balance and good compressive strength in order to avoid distortion and corrosion resistance for less need for repolishing. Of course the adequate steel selection is mandatory and that is why the WNR. 1.2083 electroslag remelted stainless steel was chosen as subject of the vacuum heat treatment process.

Results and discussions

By examining figure 1 there can be noticed that in order to achieve the best corrosion resistance a tempering around 120°C should be chosen at first glance in disfavour of a high tempering around 520 °C. Concurrently a low tempering maintains residual stresses in the material due to the fast quenching rate, further possibly increased by over tightening of tapered plugs for the cooling channels. Hence, WNR 1.2083 steel is sensitive to stress corrosion cracking. The recommendations to prevent stress corrosion cracking [17] involves, besides, the proper selection of the mold's steel, also reducing stresses and removal of corrosion favorable environments and injected materials. Since the corrosion favorable factor cannot be avoided, equilibrium between corrosion resistance and residual stresses should be achieved. For that reason a tempering temperature of 200 °C was selected and, in order to reduce the total stresses, a stress relieving was executed before the heat treatment, for canceling the stresses induces in the steel by rough machining, as presented in figure 2.

The heat treatment can influence the toughness of the mold by protective atmosphere, quenching rate and adequate quality tempering. For that reason the heating and quenching followed by two tempering were able to be executed in protected atmosphere in a Rübig® (type VH669-10 bar) vacuum furnace, while the stress relieving process could be achieved in a IVA Industrieöfen® (type VH669) vacuum furnace. DEMIG® process supervisory technology has monitored the full process parameters of both furnaces.

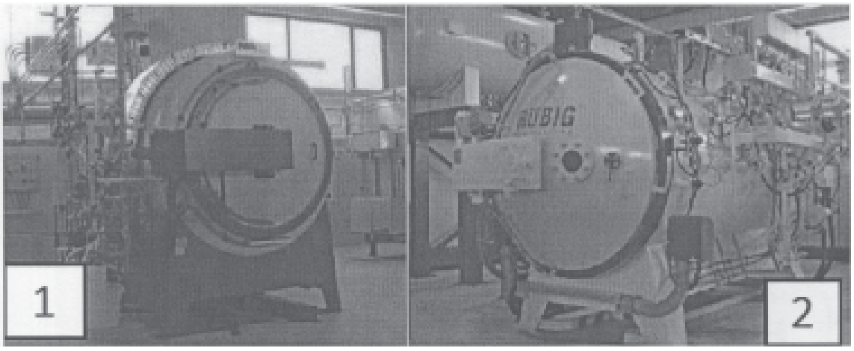

Fig. 4. Böhler Uddeholm Romania heat treatment department: 1- IVA Industrieöfen® (type VH669) vacuum furnace; 2- Rübig® (type VH669-10 bar) vacuum furnace

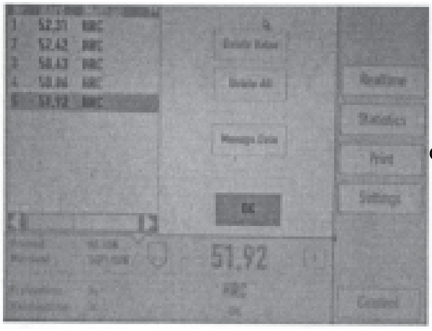

Fig. 5. Measured hardness on Rockwell type hardness tester CV-600A

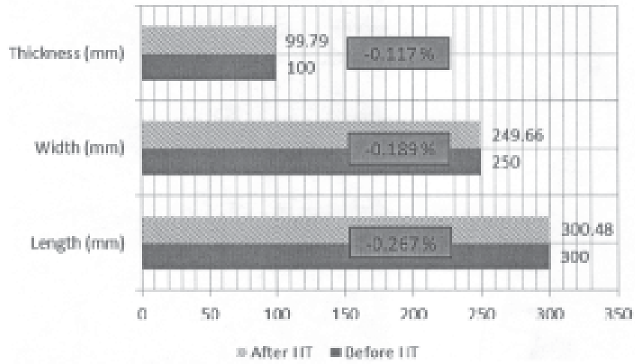

Fig. 6. Dimensional changes of the mold made out of WNR. 1.2083 ESR steel

The electroslag remelted WNR. 1.2083 steel material measured before the heat treatment the hardness of 198 HB. The annealing process followed the standard specifications and it allowed being heated for about 3 hours to 800°C, followed by a slow controlled cooling using an average cooling rate of 15 °C per hour until the temperature level of 650 °C was reached and, from that point, further cooled in air.

After rough machining the material was stress relieved and then sent to heat treatment. The heating, quenching and tempering are presented in figure 3.

The temperature inside the furnace was constantly increased until the level of 650°C was reached. Then the temperature was maintained for two hours at this level without further heating, in order for the temperatures recorded by the two thermocouples, the ambience thermocouple and the thermocouple located at approx. 1/2 the thickness of the mold, to reach the same value. Equal values were measured for approx. 30 min, after approx. 90 min of constant heating. This step heating method also serves as stress relieving. The fan located inside the furnace stopped ventilating and further sustaining the convection heating process. After 650 °C radiation heating began. The temperature level was raised again to the value of 850°C. After approx. 1 h of constant ambiental temperature of 850 °C it was possible to measure the temperature equalisation between thermocouples for approx. 25 min. Subsequently the temperature level was increased once more until austenitizing temperature of 1020°C and, after the mold reached an uniform temperature level, the soaking time was set for 30 min. The quenching was executed by using overpressurised nitrogen at 4.5 bars. The average cooling speed was approx. 17°C/min until room temperature, while between the temperatures of 500 to 800°C, it reached the value of approx. 60 °C/min. Although it is essential to avoid the perlite appearence in the structure by high cooling rates, thermal and transformation stresses should be taked into consideration in order to avoid high distorsion or even cracking.

The two tempering were consecutively accomplished in the same furnace. The steel was heated for approx. 2 h until the temperature level of 200°C was reached. After wards the process was followed by a holding time of approx. 2 h.

By using a Rockwell type hardness tester CV-600A, the hardness of approx. 52 HRC was recorded in multiple measured points as presented in figure 5.

The heat treatment process was executed in order to obtain the following properties at the temperature of 20 °C: density=7800 Kg/m^3, thermal conductivity=18 W/m °C, modulus of elasticity=190 000 MPa and specific heat=460 J/kg °C.

During heat treatment the microstructure of the steel sufferers transformations of phases and, due to the different densities, volumes, temperature behavior etc. of the three phases implied: ferrite, austenite and martensite, dimensional changes occur. Modifications in length, width and thickness are measured and recorded as presented in figure 6. Anticipated by machining allowances, these shape changes will be corrected by further grinding, followed by polishing.

Conclusions

In order to provide the long term endurance requirements for a tool used to injection molding PBT reinforced with up to 45% fiberglass, the WNR. 1.2083 steel must fulfill simultaneously the corrosion resistance, hardness, toughness, thermal conductivity, abrasive and adhesive wear resistance properties. A balance between these requirements could be achieved by high quality heat treatment that involved obtaining a hardness of 52 HRC. Reaching the right hardness may not be enough, if the microstructure does not ensure the right toughness and ductility. Although a tempering around 500°C could have been selected, the low tempering temperature of 200°C was prefered for the corrosion resistance properties to be achieved. Selection of the perfect austenitizing temperature was imperative to avoid overheating or underheating of the material. The carbide precipitation and grain growth reach correct values by the right soaking time and temperature. The over pressurized nitrogen quenching method and the presence of a process supervisory technology allowed the adequate cooling rate to be controlled and adjusted so that it could reach similar values to the nominal temperature, in order to avoid both the perlite code and distortions or even cracks provoked by transformations stresses. The right heat treatment parameters of the WNR. 1.2083 steel were presented as proper solution for obtaining the perfect material properties for the mold dedicated to injection molding PBT reinforced with up to 45% fiberglass.

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