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Development of a feedstock formulation based on PP for MIM of carbides reinforced M2

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ABSTRACT

Purpose: Influence of binder composition on some selected properties of feedstock contained powder of M2 with 10% of carbides powders are demonstrated in the paper.

Design/methodology/approach: Torque-load test, rheological tests.

Findings: Examination of the effect of the binder type and portion on structure and properties of the experimental tool materials with the cermets structure revealed that using the stearic acid reduces viscosity, thus improving technological properties of the feedstock. Employment of polyethylene instead of the high density polypropylene reduces viscosity and torque-load of the investigated feedstocks. Therefore, there is a possibility to increase the portion of the metallic or ceramic powder.

Practical implications: It is expected that further investigations of these materials will make possible their injection moulding, as well as their heat treatment increasing hardness and strength of matrix and thereby of the whole tool material. The extrusion process or PIM (Powder Injection Moulding) gives the possibility to manufacturing tools materials on the basis of high speed-steel which characterised very good properties with their final or near net shape.

Originality/value: In the paper the using extruding of the polymer-powder mix gives the possibility to fabricate cermets which, with their structure and mechanical properties, fill the gap in tool materials between the high-speed steels and cemented carbides.

Keywords: Powder metallurgy; Extrusion; Feedstock; Tool materials

1. Introduction

The binder portion in the injection moulded metallic materials is usually about 30%; whereas, it reaches 50% or more in the ceramic materials [1-10]. Regardless of the powder type increase of the binder portion reduces wear of the injection moulding machines and extruders. Regrettably, the significant binder portion is connected with the big contraction of the fabricated materials after sintering which has to be taken into account in design of the injection dies and extrusion heads. Moreover, the high binder portion or its incorrect selection and also its incomplete debinding may result in carbon content increase after sintering, compared to carbon content in the metallic powder used. Previous research of injection moulding and pressureless

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forming of the M2 and T15 steel types has revealed that both methods are applicable for fabrication of these steels; however, the thermal debinding of the thermosetting resin used for the pressureless forming is more difficult from the technological point of view and more time consuming [11-14]. Continuing investigation of the sintered tool materials one has to focus on betterment of their service properties apart from improvement of their fabrication technology [15-20]. Therefore, investigation has to be carried out to verify if homogenisation of the mix of powders during feedstock fabrication ensures its homogeneous structure, and especially the uniform distribution of carbides in the high-speed steel after sintering.

The goal of this work is selection of the proper binder and its volume portion, based on the feedstock tests of its technological properties, as well as structure and properties of the final M2 high-speed steel reinforced with hard carbides.

2. Materials and research methodology

The metal powder used for this study was a prealloyed, gas atomised M2 high speed steel with spherical shape. The 90% of the particles were less than 16 μm. The density of the M2 HSS was 8.16 g cm23, as measured with a pycnometer Micrometrics AccuPyc 1330.

A multicomponent binder was selected for this work. The binder consisted of a mixture of HDPE or PP with paraffin wax. In previous works we determined the optimal binder formulation (ref Gemma). The composition was 50% of HDPE or PP and 50% of PW. Feedstock samples with the 60, 65, 70, and 75% of M2 steel powder contents were investigated to select its optimum composition.

The carbides powder mixtures are composed by WC, TiC, TaC, and NbC. To cover the carbides surface with the stearic acid they were poured into the acid dissolved in methanol, and were churned for 30 min, so that the SA could cover uniformly carbides coatings. Next the mix was heated to temperature of 60°C to evaporate the methanol.

All the mixing processes were conducted in a Haake Rheocord Mixer252p with a pair of roller rotor blades at 40 rpm and 170ºC.

The rheological characterisation of all type of feedstock were performed in a Rheoflixer capillary rheometer (ThermoHaake) at 170 ºC over a range of shear rates from 10 to 10000 s^{-1}. The dimensions of the die were 30 mm length (L) and 1 mm diameter (D) (L/D ratio of 30).

3. Results and discussion

We prepared two feedstocks with different binder, one of them based on HDPE and the other one on PP. The maximum powder loading was 70% in volume of M2 in both cases on the basis of previous results (Ref Gemma).

Figure 1 shows the evolution of torque during the mixing process of both feedstocks. The mixture containing polypropylene has a lower torque value than the polyethylene feedstock. The steady state torque value for polyethylene feedstock (2.2 Nm) was reached after 2 hours, while in the case of polypropylene, the torque is 1Nm after a longer mixing time (3 hours).

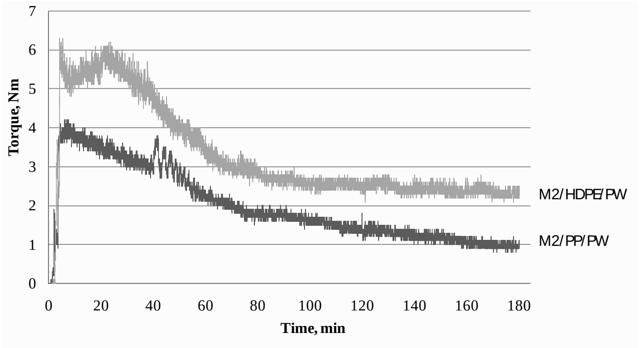

Fig. 1. Torque measurements of feedstock with 70% of M2 and two different binder compositions

One may notice that the curve for the feedstock with PP is not stable which may indicate to the non-uniform distribution of the metallic powder in the binder matrix in spite of the long homogenisation duration time. In case of the mix in which the polypropylene is used the torque decreases in the entire mix homogenisation time, i.e., during 3 hours. The correctly selected binder should moisten the powder and achieve the homogeneous state within a short time of about 30 min. Therefore, the torque curve should stabilise in this time period. To reduce the feedstock preparation time and ensure its homogeneous structure one may use the twin screw extruder or increase the binder amount. One may observe, however, analysing the torque curve for the mix in which polyethylene was used that there is no torque-load characteristics rise in spite of the lack if its stabilisation.

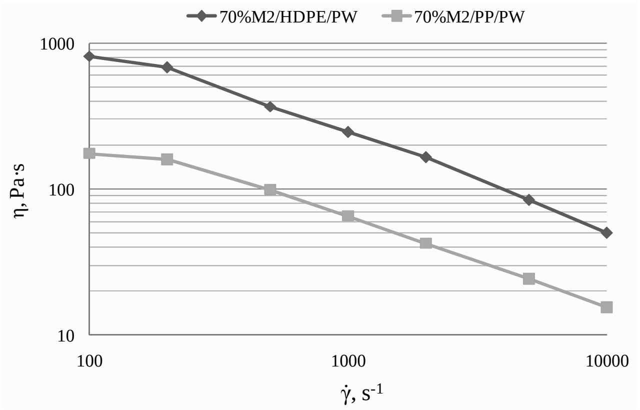

Fig. 2. Rheological behaviour of HDPE and PP based feedstocks at 170ºC

The rheological properties of feedstock are very important in order to know if the mixture can be injected. The shear rates encountered in the gates and the mold range from 100 to1000 s^{-1} for this reason most of rheological studies are made in this interval. However shear rates during injection molding can occasionally reach 10,000 s^{-1}, which is still considered suitable for injection molding. In accordance to this our rheological study was developed in this range of shear rates. Figure 2 shows the evolution of viscosity with shear rate at 170ºC. In all the cases the viscosity decreases as the shear rate increases according to a pseudoplastic behaviour. Pseudoplastic flow is often sought in the molding process to ease mold filling, minimize jetting, and help to hold component shape. As it can bee seen, the viscosity of the PP feedstock is much lower and more suitable for injection process. Taking into account that nowadays there is trends towards reinforce high speeds steels with carbides, this feedstock could be used for this purpose.

Figure 3 shows torque curves of feedstocks with different powder loadings. Higher powder loading produced higher steady state torque level, indicating differences in viscosity of the mixture. The homogenization time for the mixture slightly increased with the powder loading as a consequence of higher resistance on the rotor blades. However all the feedstock reached the steady state in a mixing time below 60 min. In the case of sample with 75 vol.% of powder, the torque value at steady state is much higher than the others mixtures and the curve is too noisy.

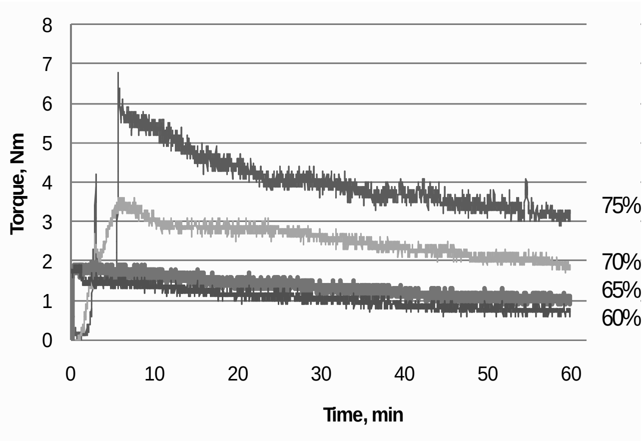

Fig. 3. Torque measurements of feedstock based on PP with different amounts of M2 at 170ºC

Moreover, an attempt to carry out the rheological tests of this polymer-powder mixture turned out to be unsuccessful due to its high viscosity. The rheological behaviour of feedstocks with powder amount of 60, 65, and 70% is shown in Figure 4. As expected the relatively viscosity of feedstocks increase with the metal volume fraction and all of them present a similar pseudoplastic behaviour. In general, during the MIM process, the shear rates can vary from 100 to 1000 s−1 and the flow rate during injection molding requires a viscosity of less than 1000 Pa s. Therefore all prepared feedstocks could be injected.

In a second step we studied the torque and rheological behaviour of mixtures of selected binder based on PP and a mixture of WC/TiC/NbC/TaC carbides. Investigations were carried out on carbides coated with the stearic acid layer to increase wettability of the carbide particles. The use of SA as the agent ameliorating wettability of the metallic and ceramic powders improves undoubtedly the feedstock technological properties. Torque evolution of mixtures with 60% in volume of carbides and different amounts of stearic acid is showed in Figure 5. Addition of 4% of SA reduces significantly the torque value to value below 2Nm. Increasing of SA portion by the next 4% results in an insignificant torque reduction; therefore, due to the negative effect of SA on the structure of tool materials its portion did not exceed 4% in further investigations.The rheological measurements of the polymer-carbides mixtures with different amount of carbides and a 4% of stearic acid are displayed in Figure 6. We can see that the viscosity increase as the amount of carbides increases. The behaviour of all the mixtures is pseudoplastic and the viscosity in the range of shear rates corresponding to injection moulding process is below 1000 Pa.s.

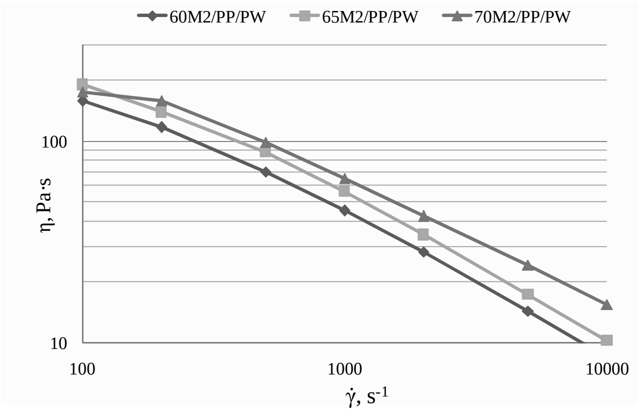

Fig. 4. Rheology curves of feedstock with different M2 powder loading

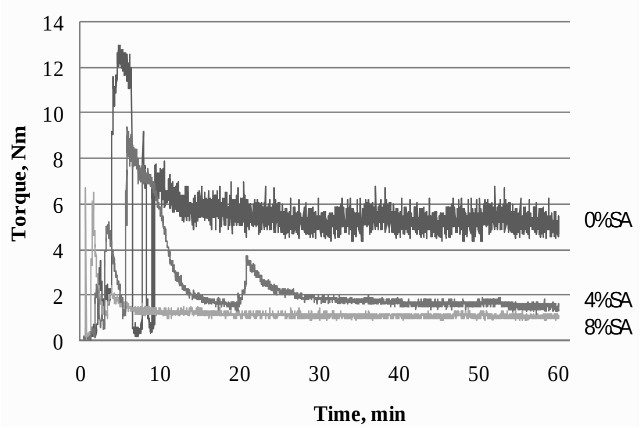

Fig. 5. Torque measurements of binder and carbides mixtures (60% in vol. of carbides) with different amounts of SA

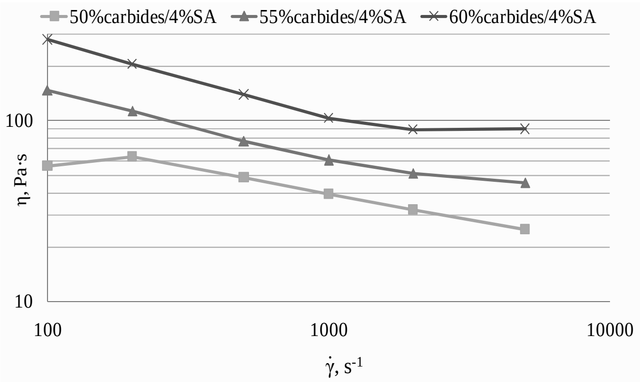

Fig. 6. Rheological behaviour of binder and carbides mixtures at 170ºC

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The rheological behaviour of this system is similar to the feedstock with M2, being probably the binder the component that govern the flow characteristics.

4. Conclusions

The use of polyethylene instead of the high density polypropylene reduces viscosity and torque-load of the investigated M2 HSS feedstocks. On the basis of torque and viscosity values the maximum M2 powder loading was 70% in volume Taking into account that nowadays there is trends towards reinforce high speeds steels with carbides, this feedstock could be used for this purpose.It is expected that further investigations of these materials will make possible their injection moulding, as well as their sintering and heat treatment increasing hardness and strength.

The torque measurements of mixtures of binder and carbides reveal that the stearic acid reduces the viscosity. The rheological behaviour of these mixtures is pseudoplastic showing that the process is controlled by the binder system.

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