INFLUENCE OF CONCENTRATION OF BINDER COMPONENTS AND BINDER MIXING IN THE RHEOLOGICAL PROPERTIES OF FEEDSTOCKS FOR POWDER INJECTION MOLDING PROCESS (PIM)

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Abstract: *The Powder Injection Molding Process (PIM) is a technique that allows the manufacture of complex parts with small dimensions and high productivity. The process involves essentially four steps, starting with mixing the powder and polymeric compound (binder - this usually composed of more than one polymer and additives), injection molding process, binder removal (debinding) and sintering. Each step can influence on final product properties. The rheology of the mixture used in injection molding is one of the most critical factors of the process and can determine its injectability. It is expected a feedstock suitable for the process to has a pseudoplastic or Newtonian rheological behavior and with low apparent viscosity. It´s difficult to obtain the mixtures used in the PIM process, because the powder concentration in the feedstock is high, and ranges between 55-70% by volume. This work studied the influences of the concentration of the binder components and method of homogenizing of a feedstock in the rheology of these. Three feedstock compositions were used and two methods of homogenization. It was observed that the rheological behavior of the mixtures is very sensitive to method of binder mixing and concentration of binder components, with changes in the rheological behavior.*

Key-Words: *Powder Injection Molding, rheology, feedstock.*

1. INTRODUCTION

Powder injection molding (PIM) is a near-net shaped processing technique that permits manufacturing of complex components. The PIM process evolved from the traditional shape-making capability of plastic injection molding and the flexibility of materials employed in powder technology. Fabrication starts by compounding a polymeric binder and powder mixture, referred as feedstock, followed by injection molding, binder removal and sintering (1,2).

Rheology has been properly defined as the study of the flow and deformation of materials, with special emphasis being usually placed on the former (3) and properties such as viscosity, elasticity and plasticity influence on the rheological behavior of fluid. The rheological properties are important in the injection molding step, since they involve the flow of the feedstock during that step. Rheological analyses can be made to quantify the stability of the feedstock during the molding process (4,5). Mixing of feedstock is an important step in this process, as the uniformity of the mixture influences the flow behavior of the feedstock and the sintered properties Concentration of binder components likewise influences the rheology behavior of feedstock.

The present paper describes the rheological behavior of three binders which has been mixed with alumina powder and two mixing method. The purpose of the investigation was to understand the influence of binder system and mixing of powder and binder to the rheological behavior of the feedstock.

2. MATERIAL AND METHOD

2.1 Material

Alumina powder of commercial purity (Almatis A 16-SG) was used in this work. Powder morphology was observed in a scanning electron microscope – SEM (Philips XL 30). The particle size distribution was measured using laser scattering particle analyzer (Cilas 1064L). The polymers used in this investigation included Latex (suspension 60%), paraffin wax, stearic acid (Sigma-Aldrch, 98%) and dicumyl peroxide. The role of each binder component is described in table 1

Table 1: Binder components.

Binder component	Function
Latex (L)	Backbone
Paraffin wax (P)	Secondary polymer
Stearic acid (AS)	Surfactant
Dicumyl peroxide (DP)	Crosslinking agent

Three binder were tested (table 2). The stearic acid and dicumyl peroxide concentration were 11.1 and 5% by weight respectively. The alumina powder content in the feedstock was 70% by volume.

Table 2: Ratio Latex/Paraffin wax

Binder	Ratio L/P
L1P1	1:1
L2P3	2:3
L1P2	1:2

2.2 Feedstock Mixing

The feedstock mixing was done by two routes. The first method (M1) was developed by stirring and heating latex, paraffin wax, stearic acid and distilled water. After all the paraffin and stearic acid melt, dicumyl peroxide was added and after complete homogenization was mixed alumina to the composition. The mixtures were stirred manually until the removal of almost all water contained in the mixture. Figure 1 shows the steps of the first method of feedstock mixing.

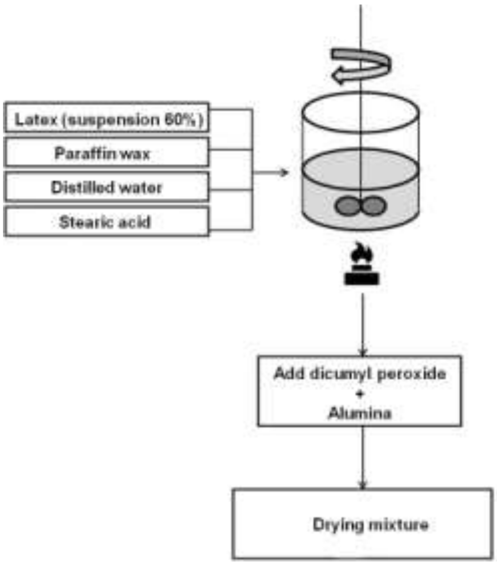

Fig 1: Method 1 (M1) of feedstock mixing.

The second method is similar to the first, wherein all steps are performed in the first method, and after the compositions are remixed in a roll mixer (MH Equipamentos)

2.3 Characterization

The viscosity of the formulations was measured using a capillary rheometer (Ceast Rheomix). The pressure drop across the length of the die (L/D = 30) was measured with a pressure transducer placed adjacent to the die entrance.

3. RESULTS

The particle size distribution of alumina is presented in figure 2. The mean size was 1.71 μm and monomodal particle distribution. The particle morphology of alumina powder is shown in figure 3.

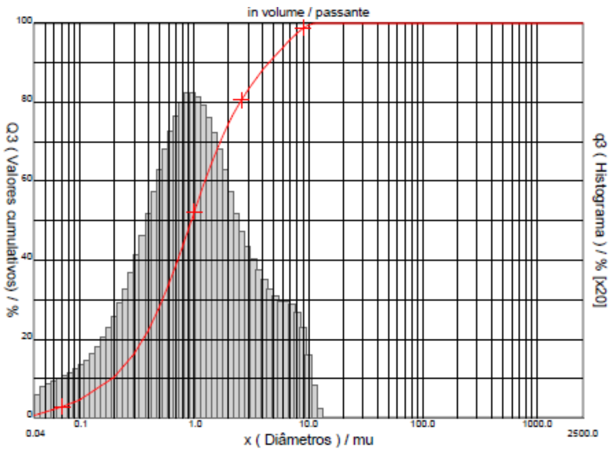

Fig 2: Alumina A-16 SG powder particle size distribution

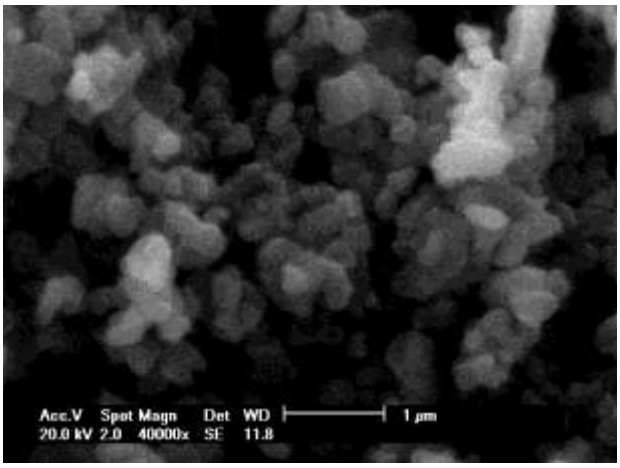

Fig 3: Morphology of the alumina powder.

The alumina particles are irregularly shape and particle size well below that observed by laser granulometry analysis. A possible cause for this discrepancy may be by formation of agglomerates.

Figure 4 shows the viscosity vs. shear rate curve for three different feedstock: (L1P1) M1, (L1P1) M2, (L2P3) M1, (L2P3) M2, (L1P2) M1 e (L1P1) M2.

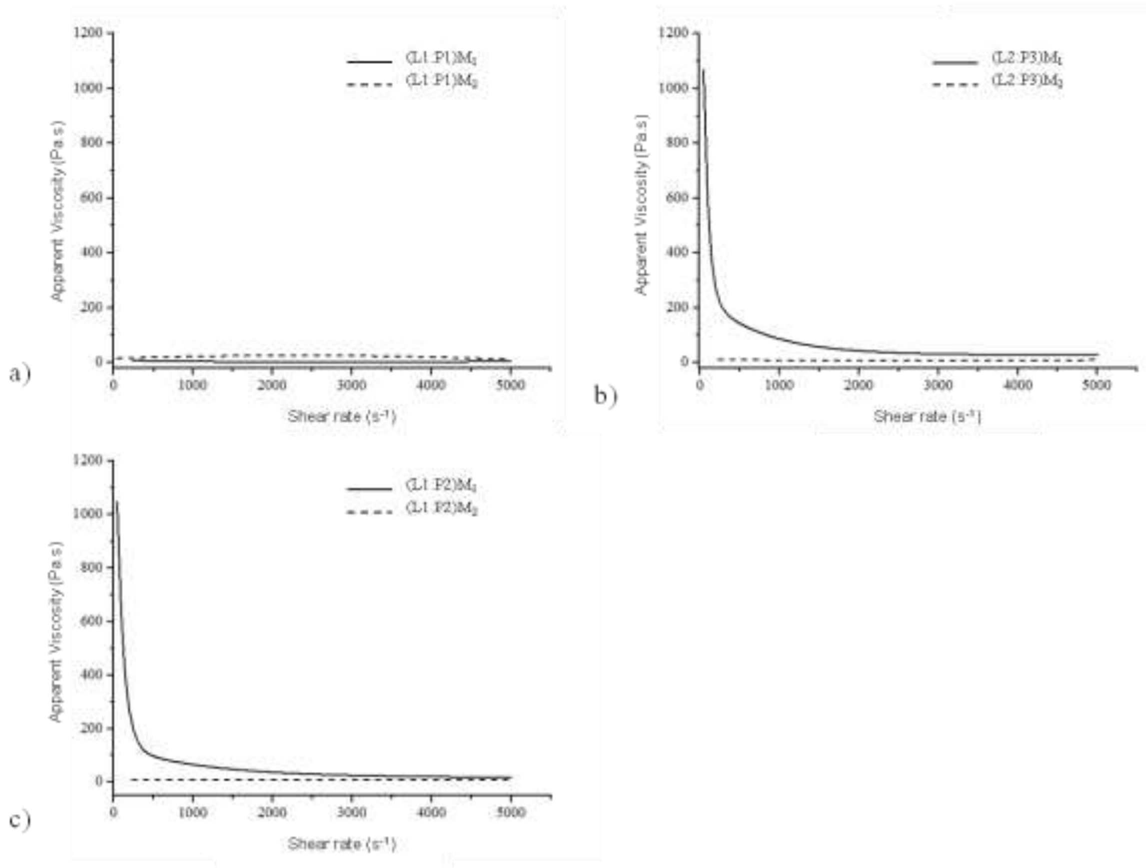

Fig 4: Viscosity vs. shear rate curve a) (L1P1) M1 e (L1P1) M2, b) (L2P3) M1 e (L2P3) M2 e c) (L1P2) M1 e (L1P1) M2.

The apparent viscosity didn`t vary significantly with shear rate increasing for (L1P1) M1, (L1P1) M2, (L2P3) M2 e (L1P2) M2 feedstock. Both had low apparent viscosity, these feedstock obtained maximum apparent viscosity of 32.33, 6.34, 10.14 and 11.41 Pa.s respectively. The curves of both exhibited Newtonian flow behavior and the viscosity remained constant as the shear rate increase. The (L2P3) M1 and (L1P2) M2 feedstock exhibited a pseudoplastic flow behavior and the viscosity decreased as the shear rate increased. According to the literature (6,7,8) pseudoplastic behavior is most suitable for the process of injection molding, particularly in fabrication of complex parts.

The mixing method affected the rheological behavior of feedstock. The rheology of the feedstock obtained by M1 showed Newtonian behavior for mixtures (L1P1) M1, (L1P1) M2, (L2P3) M2and (L1P2) M2, and pseudoplastic behavior for (L2 P3) M1 and (L1P2) M1 feedstock. The change in the rheological behavior of the feedstock (L2P3) and (L1P2) may be associated with the dispersion between the powder and binder. The M2 mixing may have generated more dispersed than M1, in addition to providing the breaking of agglomerates present in alumina particles for (L2P3) M2 and (L1P2) M2 feedstock. Some suspensions when above the critical concentration changes the rheological behavior to non-Newtonian dued to breaking of agglomerates by the shear forces , which tends to destroy the Van der Waals bonds between the particles and orientate the particles of dispersed phase in the flow direction. The reduction of these forces results in a lower apparent viscosity (9,10). So, the mixture method M2 is more efficient than M1 in breaking the particle agglomerates. The increase of temperature also helps in destabilizing those Van Der Waals forces between the particles, contributing to the reduction of agglomerates in the feedstock (9).

For PIM 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 (4). All feedstock showed low values of apparent viscosity in 100 s^{-1} shear rate of. The feedstock that exhibited pseudoplastic behavior had apparent viscosity of 542 and 576 Pa.s for (L2P3) M1 and (L1P2) M1 respectively. These values are superior to feedstock with Newtonian behavior, although fully acceptable for the PIM process. Very low viscosity are also not desired because the fluids that don`t have sufficiently viscosity when flowing into the mold can generate turbulent flow or jetting in the die cavity, resulting in voids and surface blemishes (9,10).

Figure 5 shows shear stress vs. shear rate curves of (L1P1) M1, (L1P1) M2, (L2P3) M1, (L2P3) M2, (L1P2) M1 e (L1P1) M2 feedstock. All feedstock show sligth increase on shear stress with increasing shear rate. The feedstock that exhibited pseudoplastic behavior had a yield stressof 46 kPa. The presence of yield point is due to the presence of a coagulated structure formed by the ceramic particle (9).

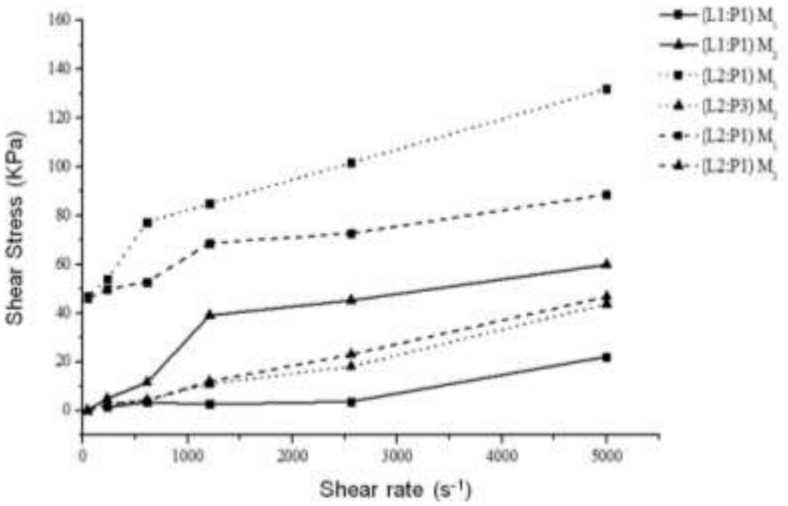

Fig 5: shear stress vs. shear rate.

4. CONCLUSION

- The rheological behaviour of three different binder systems has been evaluated. The study has shown that:
- The increase of paraffin wax ratio in the feedstock mixing for method M1 changes the rheological behavior of Newtonian to pseudoplastic.
- All feedstock evaluated are accepted for PIM process, showing Newtonian or pseudoplastic behavior.

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