Influence of binding composition on the structure and properties of steel work-pieces obtained by injection moulding

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Abstract. The paper presents the results of the research analyzing the influence of binding composition on the structure and properties of the stainless steel samples obtained by injection moulding technique. It has been determined the tailored composition of binding, which provides sufficient feedstock viscosity, low porosity of work-pieces, etc. Three binding compositions polypropylene and paraffin wax have been studied: 1:6, 1:2, 2:1, respectively. Stearic acid has been used as a SAS (surface active substance). The results have shown that the binding compositions between 1:6 and 1:2 polypropylene and paraffin wax provides sufficient viscosity feedstock, dimensional stability during debinding and sintering, and the high density of the final product.

1. Introduction

Manufacturing of work-pieces using the method of powder injection moulding (PIM) is a prospective technology [1-4]. Raw material for this technology is powders (metal or ceramic) and a binding substance. The binder is one of the most important factors, which determines the success of the production of parts obtained by injection moulding [5-7]. In most cases the binders are a mixture of organic components in which the main components are the natural waxes and synthetic polymers. Other substances may be added to modify the properties [8]. In metal injection moulding (MIM) multi-component bindings are used, one of which is a low-molecular compound and another – a high-molecular one [9]. It provides sufficient mechanical strength to a work-piece after removal of a low-molecular component of a binding substance and good gas permeability for its subsequent removal. Practically, two-component bindings with additives of surface-active substance (SAS) have found wide application [10]. The ratio of binding components may be varied, and the content of a high-molecular component may stay in the range from 80 to 20% volume ratio [11].

The aim of this paper was to establish an optimum ratio of components of binding for quality providing a feedstock and the green and sintered bodies.

2. Materials & Methods

Feedstock was produced from metal powder mixture (Table 1) and the binders with various compositions (Table 2) of high-molecular compound – polypropylene (PP) and low-molecular compound – paraffin wax. The binder № 1 contains 15% wt. PP, the binder № 2 – 35% wt. PP and the binder № 3 – 65% wt.
Contact angle of the binder was defined using formula $\theta = \frac{\theta_{\text{left}} + \theta_{\text{right}}}{2}$, where $\theta_{\text{left}}$ and $\theta_{\text{right}}$ are measured values of the superficial wetting angle on the left and right side.

Samples were produced in two stages: debinding – heating up to 550°C and holding at this temperature for two hours; sintering – heating to 1380°C and holding at this temperature for two hours.

Metallographic analysis of samples was conducted using LaboMet-I optical microscope. X-ray analysis was performed using a diffractometer with CuKa irradiation. Density of sintered samples was calculated by Archimedes method with weighing in ethyl alcohol.

Table 1. The chemical composition of the metal powder mixture

| Chemical element | C          | Cr        | Fe  |
|------------------|------------|-----------|-----|
| Concentration, % wt. | 0.16 – 0.25 | 12 – 14 | ~84 |

Table 2. Three composition of binder

| Number binder | Content, % wt. |
|---------------|----------------|
|               | Polypropylene | Paraffin wax |
| 1             | 15            | 85           |
| 2             | 35            | 65           |
| 3             | 65            | 35           |

3. Results and Discussions

Figure 1 (a) shows that increasing of the amount of polypropylene in the binder led to a higher melting temperature, from 144 to 216°C. Binder № 3 has the highest melting point, since it contains larger amount of polypropylene.

All considered binders for all selected temperatures have a contact angle less than 90 degrees (Figure 1 (b)) that means all of these binders have acceptable wetting ability. The increase of the polypropylene content in the binder leads to growth of its melting temperature and decrease of its wetting ability due to an increasing of binder viscosity. Binders № 1 and № 2 had shown almost total wetting of steel plates at temperatures 1.2· melting point, but at such temperature values can begin burning of low-molecular compound (paraffin wax).

Figure 1. Effect of the polypropylene content in the binder on the melting point – a and superficial wetting angle – b

Samples produced from feedstock with the binder № 1 and 2 (15 and 35% PP) conserved the shape after debinding and sintering, while the sample obtained using feedstock with the binder № 3 (65% PP)
deformed after debinding and had porous. Obviously this is due to insufficient content of wax in the binder, which should generate channels for removing of polypropylene degradation products during at the initial time of debinding process [12]. Therefore we did not explore the sample sintered from feedstock with the binder № 3 (65% PP).

X-ray analysis showed that samples sintered with the binder № 1 and 2 (15 and 35% PP) has α-Fe structure (Figure 2). The lattice parameters α-Fe in the samples has a similar values: 0.2876 nm in the sample of the sintered feedstock with 15% polypropylene, and 0.2871 nm – 35% polypropylene.

The values obtained for the lattice parameters are compared with iron alloying with chromium: the value of the lattice parameter of pure ferrite 0.286 nm and ferrite Fe-Cr-alloy – 0.2876 nm.

![Diffractogram from the surface of the sample after sintering at 1380°C: 1 – binder № 1, 2 – binder № 2](image)

Figure 2. Diffractogram from the surface of the sample after sintering at 1380°C: 1 – binder № 1, 2 – binder № 2

The structure of the steel after sintering with the binder № 1 (15% PP) has the form bainite (Figure 3(a)). The sample of the sintered feedstock with the binder № 2 (35% PP) has a ferritic structure with grain sizes from 24 to 96 μm (Figure 3(b)). Data of the metallographic analysis confirm results of X-ray diffraction, that the structure is α-Fe.

![Microstructure of the steel after sintering at 1380°C: a – binder № 1, b – binder № 2.](image)

Figure 3. Microstructure of the steel after sintering at 1380°C:

a – binder № 1, b – binder № 2.

Determination of density of sintered samples showed that samples, produced from the feedstock with the binder №1 (15% PP) and the binder №2 (35% PP) have densities 6.26 and 6.80 g/cm³, respectively. This represents 81-88% of the density of cast steel with analogous chemical composition.
4. Conclusion
The wettingability binder depends on its composition - increasing of high-molecular compound in the binder leads to an increase in melting temperature and decreasing of wetting angle. The optimum ratio of the components of the binder is 15:85 and 35:65 polypropylene and paraffin wax, respectively. This composition of binder provides enough viscosity of feedstock for injection moulding, preserving the shape during debinding and sintering processes, and the satisfactory density of the final product.

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