Improved tolerances by optimized powder mixes

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Abstract
Dimensional stability is a prerequisite to produce net-shape P/M components. Improved dimensional stability will make the P/M route even more cost competitive compared to competing manufacturing techniques.
Diffusion bonded powders and chemically bonded mixes are means to reduce dimensional scatter due to segregation of alloying elements. By utilizing specific bonding substances chemically bonded mixes exhibit superior flow properties that facilitate even filling of the die cavity in the press. In this presentation results are presented from a study comprising different mix compositions, type of alloying additives and use of bonded mixes, pointing out ways to improve dimensional stability.

Introduction

By bonding the alloying elements, segregation can be minimized. A common method for metallic elements such as copper, nickel and molybdenum is diffusion bonding to the iron powder particles [1, 2]. Organic binders are in general used to bond the graphite in order to minimize scatter in carbon content, but also to minimize dusting of the mixes [3]. All handling of powders may cause segregation of alloying elements. Segregation can take place on a macro scale resulting in variations from part to part but also within a component, which can result in dimensional distortion of the component. The type of alloying element has a significant impact on how prone the alloying elements in a mix are to segregate. Difference in size, density and morphology are driving forces for segregation [4].

Filling properties are also strongly influenced by the type of mix, where bonded mixes have superior properties compared to a premix [5]. Variation in the filling of the tool die can cause distortion of the components. This can be seen on components already in the green state, for example as variation in height or out of roundness of a ring shaped component.

In this paper a bonded mix (Starmix™) is compared to a non-bonded mix regarding powder properties characterized by a number of different methods. Results are presented from a production trial where the following comparisons are made:

- Non-bonded mixes (Premix) versus bonded mixes (Starmix™)
- Elemental copper powder versus diffusion bonded copper additive (Distaloy™ ACu)

Experimental
Mixes of the following nominal composition are used to exemplify different properties of a bonded mix (Starmix™) in relation to a non-bonded mix (Premix):

ASC100.29 + 2% Cu-100 + 0.8% C-UF4 + 0.8% Lubricant

The two types of mixes are:
• Premix containing amide wax as lubricant
• Starmix™ containing an amide wax based lubricant/binder composition

Flow and apparent density of the mixes were evaluated according to standards ISO 4490 and ISO 3923 respectively.

Dusting
A dust track aerosol monitor was used to measure dusting of the powder mixes. Five grams of powder flow from a Hall funnel into a sample container. Air from the container is extracted by a rate of 1.7 dm^3/min and fine particles in the extracted air are monitored.

Bonding of graphite
The bonding degree of graphite was measured with an air classifier, Roller Air Analyzer from Aminco. The parameters were set to separate graphite particles with a particle size of 4μm. The sample weight was 50g. The graphite content was measured before and after operation in order to calculate the bonding degree as follows (1):

(1) $$\frac{C_2}{C_1} \times 100 = \text{Bonded graphite (\%)}$$

C_1 = Analyzed graphite before test
C_2 = Analyzed graphite after test

Die filling simulation
Equipment for simulation of die filling performance was used to evaluate the mixes. The equipment has eight cavities with varying widths between 1 mm and 20 mm, having a fixed length and depth of 30 mm, see figure 1.

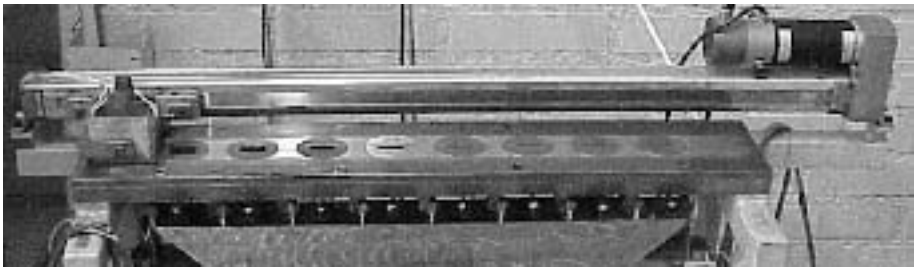


Figure 1: Die Filling Simulator

A more detailed description of the equipment is found in [5]. The cavities are filled in sequence at different fill shoe velocity and the powder from each cavity is subsequently collected and weighed. Based on the weight of the powder and volume of the cavity, a filling density is calculated for each cavity. A Filling Index is defined in order to simplify

interpretation of the results. Filling index is calculated according to equation 2 and is plotted versus the filling velocity.

$$\frac{AD_{13mm} - AD_{2mm}}{AD_{13mm}} \times 100 = \text{Filling index (\%)} \quad (2)$$

Production trials

Mixes included in the production trials all have the same nominal composition:
ASC100.29 + 2% Cu + 0.8% C-1651 + 0.8% Lubricant

All mixes are based on a water atomized pure iron powder, ASC100.29. Two different types of copper additives are included, one is a water atomized copper powder designated Cu-165. The other is Distaloy™ ACu, which is a master alloy powder with 10% fine copper diffusion bonded to a pure iron powder. All mixes contain graphite C-1651 and 0.8% lubricant; amide wax in premixes and an amide wax based lubricant/binder system in Starmix™. Attributes of the mixes are presented in table 1.

Table 1: Composition of investigated materials

Mix number	Mix type	Type of Cu additive
1	Premix	Cu-165
2	Starmix™	Cu-165
3	Premix	Distaloy™ ACu
4	Starmix™	Distaloy™ ACu

To evaluate the performance of the mixes small 28 teeth gears were pressed in a 100 ton Gasbarre press. Outer diameter of the gears is 43 mm, inner diameter is 21 mm and the height is 12 mm. The set value for the density was 7.0 g/cm³. The speed of the press was set to 16 strokes per minute and of each mix 750 gears were pressed. Groups of 5 gears were sampled for each 25 gears pressed. Components were sintered in a production furnace at 1120°C for 20 minutes in 90/10 N_2/H_2 atmosphere. The sampled specimens were weighed and measured with respect to outer diameter and ovality of the outer diameter, calculated as the difference in diameter in two perpendicular directions.

Results and discussion

Flow and apparent density of the mixes are presented in table 2. It is seen that the flow is 9 seconds faster for the Starmix™ compared to the premix. Apparent density is 0.15 g/cm³ higher for the Starmix™.

Mix type	AD (g/cm³)	Flow (s/50 g)
Premix	2,97	33,8
Starmix™	3,12	24,9

Table 2: AD and flow of mixes

Dusting

Result of dusting test is presented in figure 2. Starmix™ gives less dusting of fine particles, predominantly graphite, compared to a Premix. By reducing the dust formation, working environment around presses is improved.

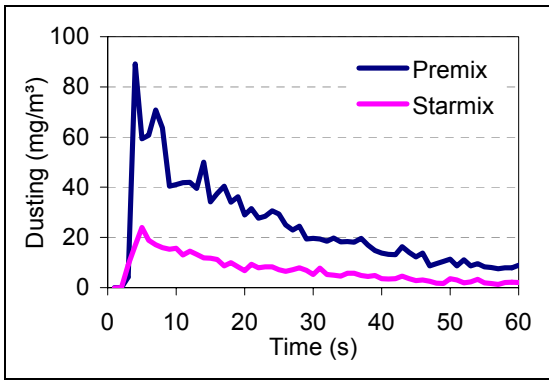


Figure 2: Dusting of mixes

Bonding of graphite

Bonding of graphite serves for good control of carbon content in sintered components. To have a close control of carbon content is a pre-requisite for small dimensional scatter in many alloying systems, not at least the iron-copper-carbon system where carbon is counteracting the copper growth. By using Starmix™ close to 100% of the graphite is bonded to the iron powder particles, see table 3.

Table 3: Bonding of graphite by Roller

Mix type	Degree of bonding
Premix	55%
Starmix™	98%

Die filling simulation

Filling index is presented versus the fill shoe velocity in figure 3, where two observations are made. Starmix™ gives a lower filling index which means that the difference in fill density between wide and narrow cavity is smaller, the powder will thus fill a cavity with complicated geometry more homogeneously. At the highest velocity the filling index is rapidly increasing for the Premix due to not complete filling of the narrow cavities. Starmix have the same filling index at all investigated velocities. This means that even at the highest velocity all cavities are completely filled.

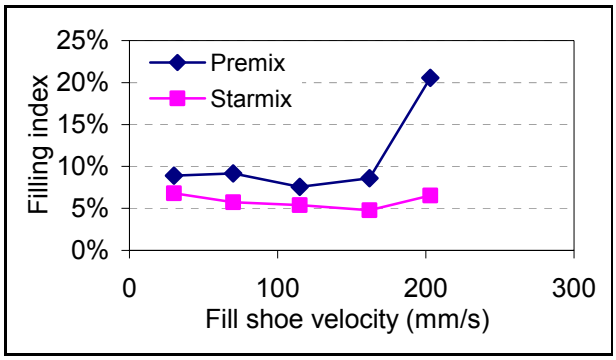


Figure 3: Filling index

Production trials

The scatter in weight of green gears is presented in figure 4. The good filling behaviour of Starmix™, illustrated in the die filling simulation, serves for a decreased weight variation during compaction. Still, the compaction speed applied in these trials was at a level, where the filling characteristics for the Premix are acceptable. The positive effect of using a bonded mix would be even more pronounced at higher compaction speeds [6].

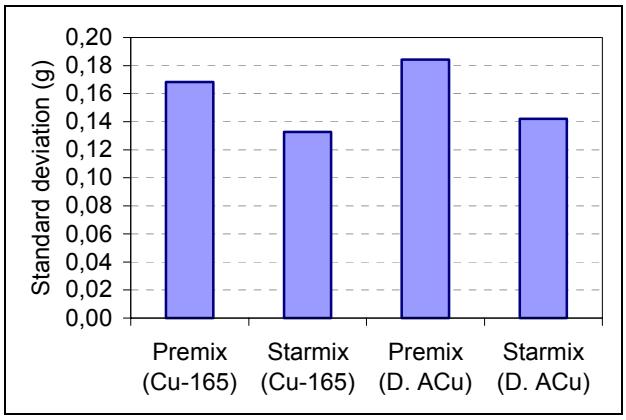


Figure 4: Green weight scatter

In figure 5 the ovality of the gears in green and sintered state is presented. By using Starmix™ instead of Premix the roundness of the gears is improved in both green and sintered state. The better roundness for the bonded mix is explained by a more homogenous density distribution, due to more even filling of the press tool die.

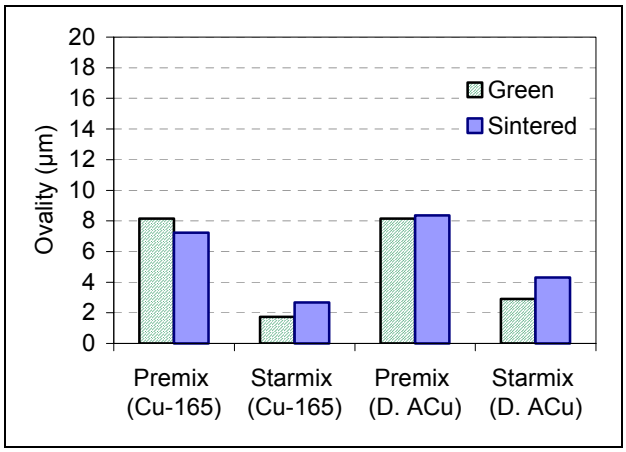


Figure 5: Ovality of green and sintered gears. Diameter 1 – Diameter 2.

In figure 6, the variation in the sintered diameter, parallel to the filling shoe direction, is presented as one standard deviation. Also in this case the bonded mixes have less scatter compared to the corresponding Premix. An effect of using Distaloy ACu as copper additive instead of elemental copper powder is less dimensional scatter, both in the case of Premix and Starmix™. The improved dimensional control when using Distaloy ACu is explained by less variation in copper content of the sintered gears.

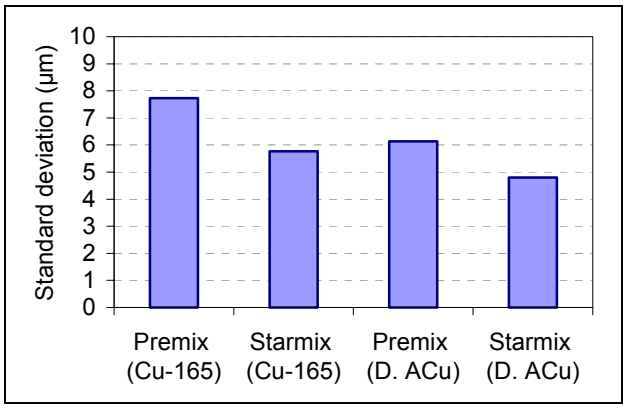


Figure 6: Standard deviation of outer diameter of sintered gears

Final tolerances of a P/M part are dependent on the filling performance of a powder mix as well as the chemical composition within and between components. Starmix™ is optimized to achieve maximum bonding of alloying elements and superior filling characteristics. In the present study it is shown that utilizing a bonded mix in combination with a diffusion-bonded copper grade can optimise the final tolerances, in terms of dimensional stability and roundness.

Conclusions

With bonded mixes dusting is significantly decreased, better carbon control in sintered parts is enabled and powder properties are improved.

The better flowability of bonded mixes enables filling of narrow sections as well as higher productivity by increased press speed.

Improved dimensional accuracy is achieved by using Starmix™ and Distaloy™ ACu as copper additive.

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