DIFFERENT MEANS TO IMPROVE CONSISTENCY OF MATERIAL PROPERTIES AND TOLERANCES OF LOW-ALLOYED PM STEELS

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The strength of the P/M technique is to produce components to net shape. Even if the components are pressed to final shape additional machining or sizing operations are in many cases needed to achieve the desired tolerance class. These additional operations increase the production costs. If dimensional scatter can be reduced the P/M route to produce components becomes more competitive in comparison with other manufacturing techniques. Different alloying techniques are available in powder metallurgy. Alloying elements can be admixed, organically bonded in the mixes, diffusion bonded to the iron powders or pre-alloyed. Often combinations of these techniques are utilized. These techniques have different pros and cons with respect to compressibility, dimensional stability and mechanical properties of the sintered material. In this presentation a comparison of different alloying techniques is made focusing on dimensional stability.

INTRODUCTION

In plain mixes with alloying elements added as elemental powder difference in size, density and morphology of these different powders may cause a risk of segregation. With segregation, dimensional scatter of the sintered components increases. An alternative, for some alloying elements, is to pre-alloy the powders with alloying elements added to the melt before atomizing. Pre-alloying has the draw back that all alloying elements, to varying extents, decrease the compressibility of the iron powder. In the early seventies diffusion alloyed powders, Distaloy®, were introduced to the market. Distaloy powders are iron powders with diffusion bonded Cu, Ni and Mo. This type of powders has proven to give high strength material with good dimensional stability. By utilizing diffusion bonding, alloying elements with finer particle size can be used without risk of segregation. Compressibility is only decreased to a very limited extent by the alloying additions in distaloy powders. In the mid-eighties mixes with organic binders to avoid segregation of non-metallic elements such as graphite were introduced. With developments in binder techniques, metallic elements of fine particle size are also possible to bond.

SEGREGATION

Segregation of powder can be broadly classified into five processes and several mechanisms [ref. 1]. The segregation processes are:

- Heap segregation
- Percolation
- Displacement segregation
- Fluid segregation
- Impact segregation

When handling powder mixes for production components heap segregation is an important mechanism. In this paper experiments and discussion are focusing heap segregation, which is occurring during filling of a hopper for example. Heap segregation can be further sub-divided into a number of mechanisms. Rolling and Sieving are likely the most important in segregation of P/M powder mixes. Rolling is the phenomenon that larger particles are rolling on the surface on a heap. Finer particles are over represented in the center of a pile while coarser particles are concentrated to the edge of the pile. Sieving mechanism is when larger particles are rolling down, the surface acts as a non-blinding screen, through which the finer particles can find their way.

A number of particle properties affect the motion of particles and are consequently able to affect the segregation [1]. These properties are:

- Size
- Density
- Shape
- Module of elasticity
- Friction coefficient
- Adhesion

Difference in size is common in the case P/M powder mixes. Alloying elements are commonly finer compared to the base powder. Different manufacturing processes results in different particle morphology from round to irregular shapes. Graphite and lubricant, which are present in virtually all mixes for P/M applications, are both much finer in size and have a much lower density compared to the base powder.

Experimental

The segregation tester consists of an inclined plane where the powder slowly flows from a powder inlet on the top, see figure 1. The angle of the plane is adjusted to match the angle of repose of the powder to be tested. A layer with uniform thickness is forming on the plane as the powder is flowing into the tester. Samples are taken on five different positions with the sampling tubes. These samples are analyzed for the property of interest, which can be concentration of an additive or size distribution or other properties.

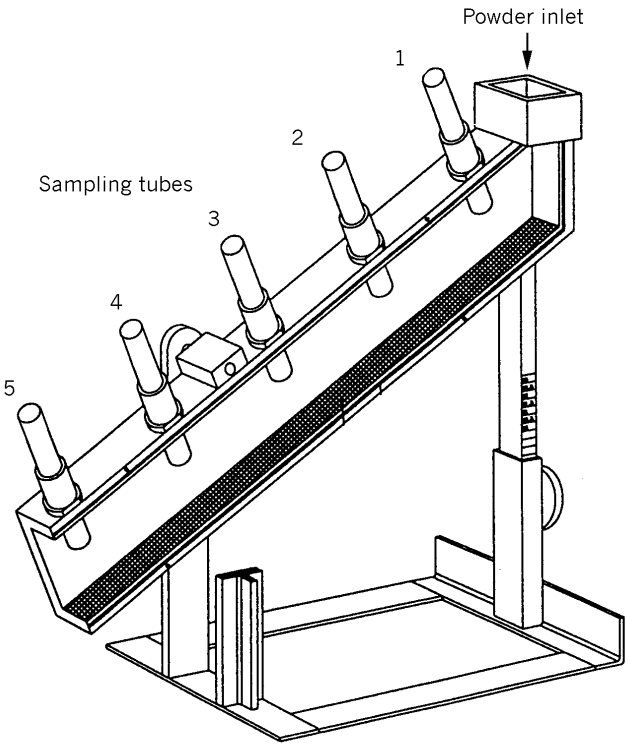


Figure 1: Segregation testing apparatus

In this paper two investigations are presented. The first is a comparison of different types of copper additive. Four mixes with the composition NC100.24 + 3% Cu + 0.5% Graphite + 0.8% H-wachs are tested with respect to sensitivity to segregation of copper. In the four mixes different copper additives are used, namely:

1. -100 mesh atomised copper powder
2. -200 mesh atomised copper powder
3. -325 mesh electrolytic copper powder
4. Distaloy Cu (10% fine particle size copper diffusion bonded to a sponge iron powder)

Copper content in the samples from the five levels is compared. This investigation illustrates the influence of particle size, shape and bonding.

The second investigation aims to illustrate the influence of flowability of powder mixes and the flowrate of the powder. For this purpose three mixes with same nominal chemical composition were prepared. All three mixes were based on ASC100.29 atomized iron powder with 2% Cu, 0.5% C-UF4 graphite and 0.8% amide wax added. Mix 1 is an ordinary mix while mix 2 and 3 are organically bonded experimental mixes. Mix 2 and 3 only differ in flowability but are similar in other respects. In table 1 powder properties of the mixes are presented. A clear difference in flowability, measured as Hall flow, is seen. The two bonded mixes have to different extent improved flowability.

Table 1. Powder properties of powder mixes

Mix	Hall Flow (s/50g)	AD (g/cm^3)	GD @600MPa (g/cm^3)
1	31.7	3.19	7.09
2	28.0	3.00	7.13
3	24.7	3.05	7.11

To make the experiment at different flow rates two inlets were used; one with a width of 2 mm and the other with a width of 5 mm.

Results and discussion

In figure 2 the results from the first of the segregation investigations is presented. The results are not directly corresponding to a real situation in handling and pressing components in terms of levels of alloying elements, but it does however give a good comparison of how sensitive different mixes are to segregation.

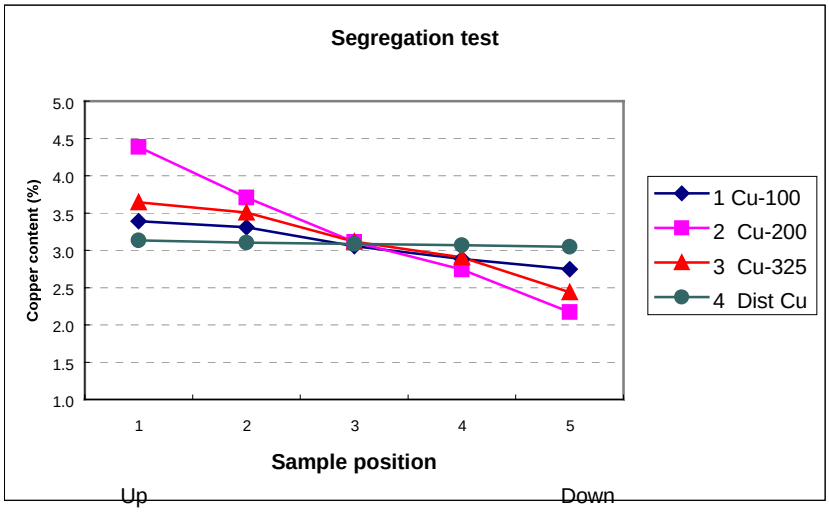


Figure 2: Results from segregation test

The results are clearly showing a difference between the copper additives in the investigation. A comparison of the two atomized copper powders, Cu-100 and Cu-200, shows how the particle size influences the sensitivity to segregation. The mix with -200 mesh copper powder is much more inclined to segregate compared to the mix with -100 mesh copper powder.

Comparing the electrolytic copper powder, Cu-325, with the two atomized copper powders shows the influence of morphology of the particles. Even though Cu-325 is finer in particle size than Cu-200, Cu-325 is less inclined to segregate due to the more irregular particle shape.
Best in the investigation is the mix with copper added as Distaloy Cu, where the copper powders are diffusion bonded to an iron powder. The mix exhibits almost no segregation with respect to copper content in the segregation tester. By selecting additives that make the mix less inclined to segregate, dimensional variations due to varying content of alloying elements can be kept to a minimum.

Results from the second of the segregation investigations are shown in figure 3 and 4. In this investigation the amount of particles finer than 45 µm is measured. A fundamental principle for segregation is illustrated in these results. A powder with better flowability is more inclined to particle segregating compared to a powder with poorer flowability. Material 1, that has poor flowability, exhibits least particle segregation. Material 3 that has best flowability of the three mixes also is the mix that exhibits most particle segregation. This implies that powders with good flowability must be handled with more caution than a powder with less good flowability.

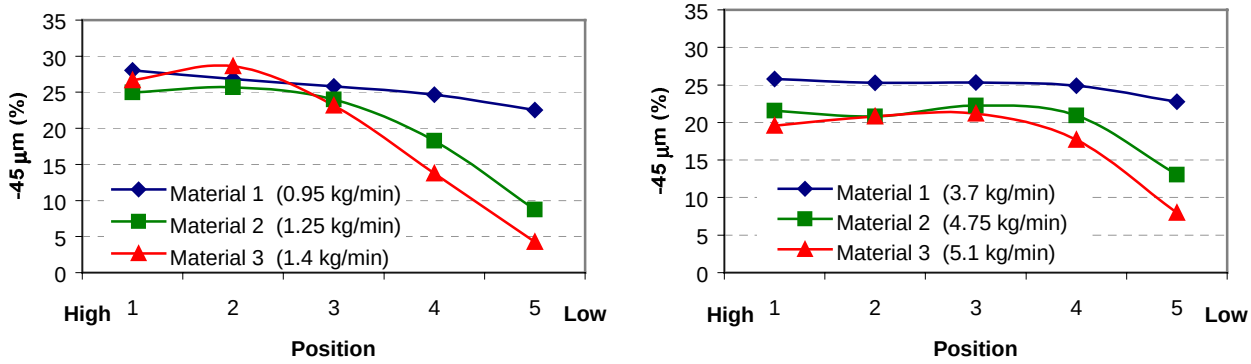


Figure 3 and 4: Particle segregation - Inlet 2 mm (left) and 5 mm (right)

A factor that is important is the flow rate when powder is handled. In the legend of diagram 3 and 4 the flow rate during the segregation test is indicated. These flow rates were calculated based on the time for 3 kg of powder to flow through the inlet of the segregation tester. By increasing the inlet size the mass of powder per minute flowing into the tester is increased by a factor 3 - 4. With the larger inlet particle segregation is significantly decreased.

Bonding of alloying elements

Two mixes with same nominal chemical composition were prepared for the investigation. Both mixes are based on ASC100.29 atomized iron powder with 2% Cu, 0.5% C-UF4 graphite and 0.8% amide wax added.

1. ASC100.29 + 2% Cu -200 mesh + 0.5% C-UF4 + 0.8% Amide wax
2. ASC100.29 + 2% Cu-25 + 0.5% C-UF4 + 0.8% Amide wax

Mix 1 is an ordinary mix while mix 2 is an organically bonded experimental mix. To illustrate the degree of bonding, particle size distribution of the mixes was measured by laser diffraction (Sympatec). In figure 5 the cumulative particle size distributions for the mixes are presented. By bonding the fine particles to the coarser a significant decrease of free fine particles is obtained. From the low amount of fine particles measured it can be concluded that graphite as well as the fine particular copper additive are bonded to the base iron powder.

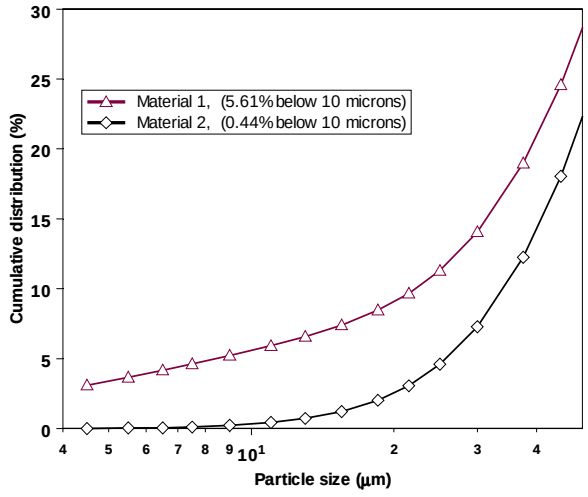


Figure 5: Cumulative particle size distribution by laser diffraction

This type of bonding system will decrease segregation of alloying elements caused by difference in size, morphology and density of the alloying particles and the base powder.

SENSITIVITY

One way to improve dimensional stability is to decrease variations in chemical composition to get good control over the density and process variables. Another way to decrease dimensional scatter is to select material that is less sensitive to variations likely to occur in the manufacturing process. For different applications and manufacturing processes different parameters are critical. This is important to consider if less dimensional scatter is desired.

Table 2: Type and composition of base powders

Base powder	Type of powder	Cu	Ni	Mo
ASC100.29	Atomized			
NC100.24	Sponge			
Distaloy AE	Atomized	1.5% (D)	4% (D)	0.5% (D)
Distaloy DC-1	Atomized		2% (D)	1.47% (P)
Distaloy HP-1	Atomized	2% (D)	4% (D)	1.47% (P)

To illustrate a comparison between some commonly used alloying system is made in this part of the paper. The materials compared are based on the powders in table 2. Impact of combined carbon content and sintered density on the dimensional change is presented in figure 6 and 7. Data in the two charts origin from [ref. 2]. Dimensional change is measured from green to sintered specimen on TS-bars according to ISO 2740. In figure 6 specimens were compacted at 600 MPa while different compacting pressure in the range from 400 to 800 MPa were used to generate the data in chart 7. Sintering was made at 1120°C, 30 min in endogas with carbon potential set by methane addition. Exceptions to these parameters are Distaloy HP-1 that was sintered at 1120°C, 40 min in DA atmosphere and in figure 7 ASC100.29 + 0.45% P that was sintered in DA atmosphere.

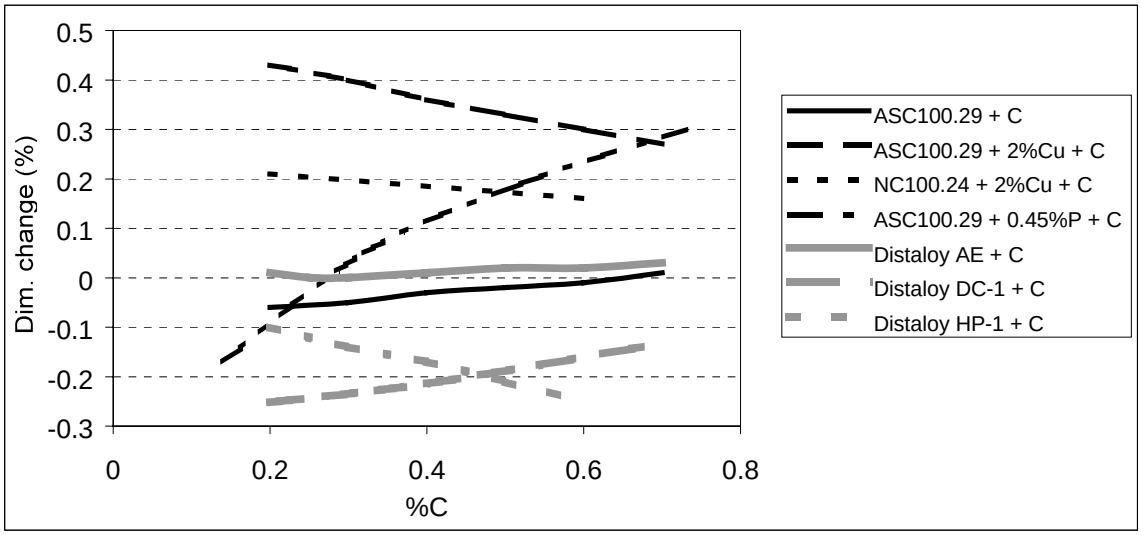


Figure 6: Dimensional change versus carbon content

For a pure iron powder increased additions of carbon cause the material to shrink less, see ASC100.29 + C in figure 6. If copper is included it is well known that a material that grows during sintering is obtained, see material ASC100.29 + 2%Cu + C and NC100.24 + 2%Cu + C. With increased copper content the material grows less with increased carbon content. It is also of interest to compare material based on sponge (NC100.24) and atomized (ASC100.29) base powder. It is

seen that the sponge-based material grows less during sintering but as well the impact from carbon content on dimensional change is smaller.

With phosphorous as alloying element (ASC100.29 + 0.45%P + C) a shrinking material is obtained [ref. 3]. In figure 6 it is seen that increased carbon content is strongly counteracting the shrinkage of material with this alloying system. With carbon content above 0.2 – 0.3% a growing material is obtained.

Distaloy AE is a high strength material with good dimensional stability. One reason of the good dimensional stability can be seen in figure 6. Dimensional change is almost independent of carbon content. Distaloy HP-1 is a material that achieves a tensile strength of more than 900 MPa already after sintering at 1120°C [ref. 4]. With increased carbon content the material shrinks more while Distaloy DC-1 shrinks less with increased carbon content.

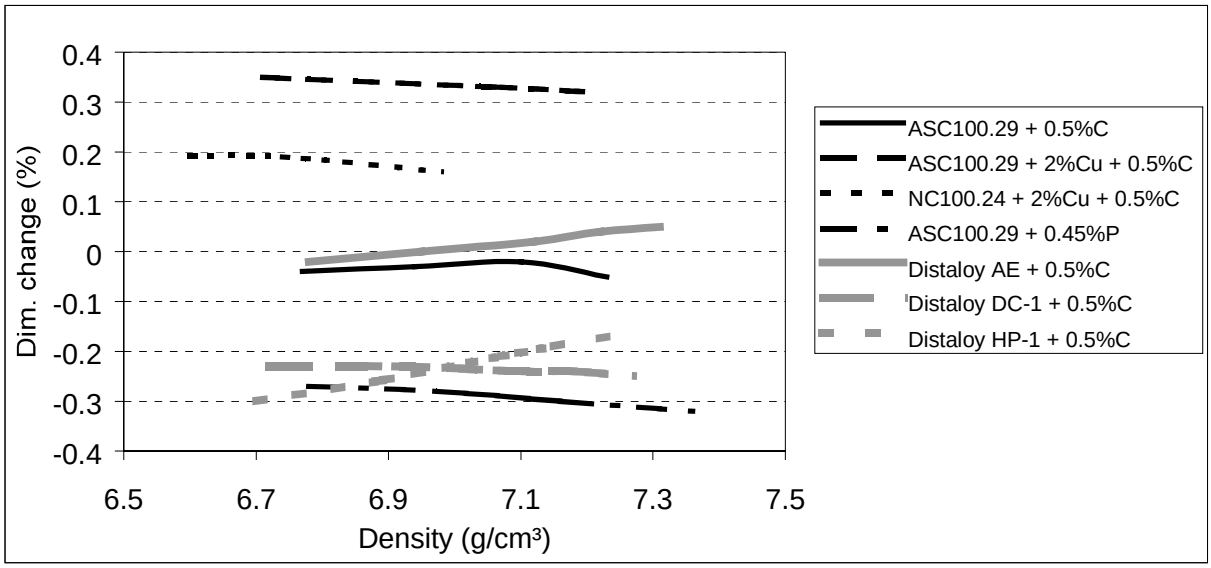


Figure 7: Dimensional change versus density

In figure 7 dimensional change versus sintered density is presented. It is here seen that Fe-C, Fe-Cu-C and Fe-P materials are relatively insensitive to density variations. Distaloy AE and Distaloy HP-1 are shrinking less/growing with increased density. For certain types of components such as synchronizing hubs density variations within the components are difficult to avoid. These density variations are causing dimensional distortion after sintering if a material with density dependent dimensional change is used. The need for a high strength material with dimensional change independent of density was identified. Distaloy DC-1 was developed to fulfill this need [ref. 5]. As it is seen in the figure dimensional change of Distaloy DC-1 is independent of density.

CONCLUSIONS

More consistent chemical composition of the components will result in less dimensional scatter. Ways to obtain more consistent chemical composition are suggested. Utilizing additives less prone to segregate is one way to improve consistency. Bonding the alloying elements to the base powder is another way to decrease segregation where diffusion bonding and use of organic binders are two possibilities.

High flowability is desired to obtain efficient filling of the tool die. The drawback of improved flowability is that the powder is more inclined to particle segregation. Rapid and streamlined handling of powder minimizes particle segregation and should be used to get optimal result.

Impact of carbon content and density for a number of alloying systems has been discussed in this paper. This aims to exemplify how different alloying systems are sensitive to different parameters. One conclusion is that it is of great importance to keep the parameters under control, which has strong impact on the dimensional change.

When selecting the material, sensitivity to variations in composition, density and processing conditions should be considered.

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