# MECHANICAL PROPERTIES AND DIMENSIONAL STABILITY OBTAINED WITH DIFFERENT ALLOYING TECHNIQUES

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Alloying elements can be added in different ways to metal powders. Admixed, with or without addition of binder, pre-alloyed and diffusion bonded alloying elements are commonly used in the industry. The way of adding the alloying elements influences mechanical properties of the material. Dimensional scatter after sintering is another important characteristic of the material that is influenced. Good dimensional stability after sintering is a way to avoid the need for secondary operations such as sizing and machining. In this presentation, properties of materials with similar alloying content but utilizing different alloying techniques are presented. Both mechanical properties and dimensional stability are investigated and discussed.
KEYWORDS: ALLOYING, STRENGTH, DUCTILITY, DIMENSIONAL STABILITY

## INTRODUCTION

In plain mixes with alloying elements added as elemental powders 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. In this paper materials with similar composition to Distaloy AE but utilizing organic binder and/or pre-alloying are discussed. Mechanical properties and dimensional stability with the organically bonded/pre-alloyed materials are compared with Distaloy AE.

## EXPERIMENTAL

A premix based on Distaloy AE with 0.5% graphite C-UF4 and 0.8% amide-wax is compared with materials of similar alloying composition but utilizing organic binder, pre-alloying or combinations of these two techniques. The nominal alloying content is 1.5% Cu, 4% Ni, 0.5% Mo and 0.5% C with the exception that material 2 does not contain Mo and material 4 – 6 contain 0.85% Mo. In table 1 the alloying technique and types of Cu additives are indicated.

*Table 1. Investigated materials*

| | Alloying technique | | | | |
|---|---|---|---|---|---|
| Mtrl | Cu | Ni | Mo | Basepowder | Cu type |
| 1 | D | D | D | Distaloy AE | Diffusion alloyed |
| 2 | A | A | - | ASC100.29 | -25 µm |
| 3 | A | A | A | ASC100.29 | -25 µm |
| 4 | A | A | P | Astaloy 85 Mo | -150 µm |
| 5 | A | A | P | Astaloy 85 Mo | -75 µm |
| 6 | A | A | P | Astaloy 85 Mo | -25 µm |
| 7 | P | P | P | Experimental | Pre alloyed |

*Letter refers to alloying technique:*
*D = Diffusion bonded, P = Pre-alloyed,*
*A = Admixed with organic binder*

TS-bars (ISO 2740) and IE-bars (ISO 5754) were compacted at 600 MPa of the powders in table 1. Material 7 was warm compacted at 800 MPa to compensate for the lower compressibility. Specimens were sintered at 1120°C, 30 minutes in 90/10 $N_2/H_2$ with methane addition in a laboratory belt furnace. The cooling rate was ~0.85°C/s.

The influence on dimensional change from variations in density, copper, nickel, carbon, sintering temperature and sintering time was investigated by using DOE, Design Of Experiment, technique to set up and evaluate the experiments. The more influence these parameters have on the dimensional change, the more dimensional scatter can be expected.

## RESULTS AND DISCUSSION

In table 2 and 3 chemical analyses and mechanical properties of the sintered specimens are presented.

*Table 2. Chemical analysis and density on sintered specimens*

| Mtrl | Cu (%) | Ni (%) | Mo (%) | C (%) | SD (g/cm³) |
|---|---|---|---|---|---|
| 1 | 1.47 | 4.03 | 0.50 | 0.50 | 7.08 |
| 2 | 1.47 | 3.92 | 0.00 | 0.51 | 7.10 |
| 3 | 1.45 | 3.99 | 0.50 | 0.54 | 7.10 |
| 4 | 1.61 | 4.04 | 0.80 | 0.56 | 7.05 |
| 5 | 1.58 | 4.02 | 0.81 | 0.56 | 7.05 |
| 6 | 1.59 | 4.01 | 0.78 | 0.53 | 7.11 |
| 7 | 1.51 | 3.98 | 0.54 | 0.64 | 6.83 |

Chemical compositions of the sintered specimens are close to the nominal values besides combined carbon after sintering that is somewhat higher for material 7. Sintered density is in the range of 7.05 and 7.11, except for sample 7 that is fully pre-alloyed.

*Table 3. Dim. change and mechanical properties*

| Mtrl | DC (%) | HV10 | TS (MPa) | YS (MPa) | A (%) | IE (J) |
|---|---|---|---|---|---|---|
| 1 | -0.14 | 225 | 744 | 399 | 2.5 | 27.0 |
| 2 | -0.04 | 178 | 531 | 330 | 2.3 | 26.7 |
| 3 | -0.02 | 190 | 581 | 335 | 2.1 | 27.9 |
| 4 | 0.05 | 249 | 630 | 452 | 0.7 | 12.7 |
| 5 | -0.02 | 236 | 687 | 450 | 0.9 | 16.2 |
| 6 | -0.13 | 258 | 780 | 467 | 1.2 | 25.8 |
| 7 | -0.23 | 382 | 535 | 453 | 0.28 | 11.7 |

By comparing sample 1 – 3 and 6 influence of Mo addition can be studied, see figure 1. The sample without Mo addition has 200 MPa lower tensile strength compared to the diffusion alloyed material. Admixing Mo powder has little influence on the mechanical properties. By pre-alloying molybdenum tensile strength as good as and yield strength exceeding those of diffusion alloyed material is obtained.

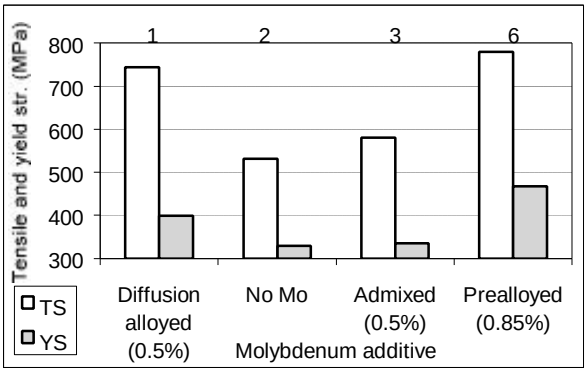



Figure 1. Tensile and yield strength with different types of Mo additions

Impact energy is quite similar for the materials with different molybdenum additive, see figure 2. Addition of Mo powder decreases elongation slightly compared to the material without Mo. By pre-alloying 0.85% Mo elongation is further decreased to half the level of the diffusion alloyed material.

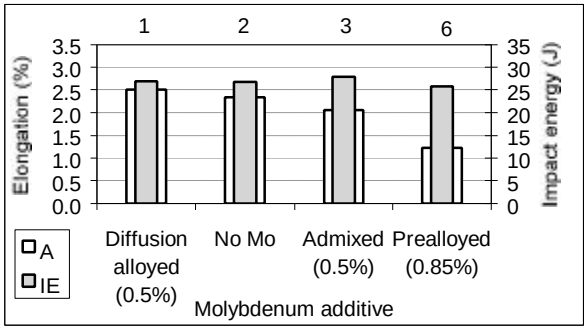



Figure 2. Elongation and impact energy with different Mo additions

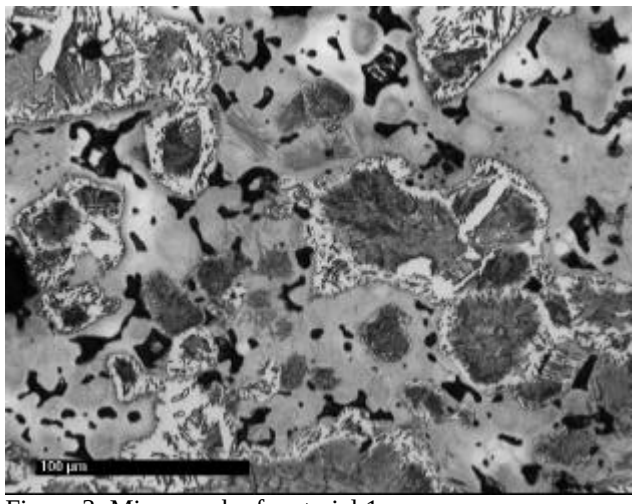


Figure 3: Micrograph of material 1

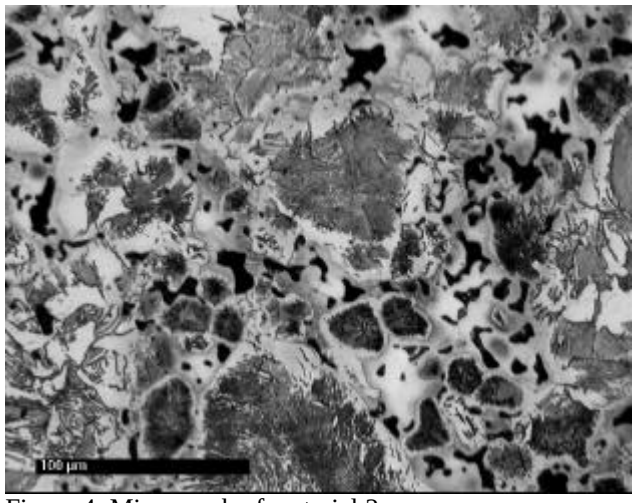


Figure 4: Micrograph of material 2

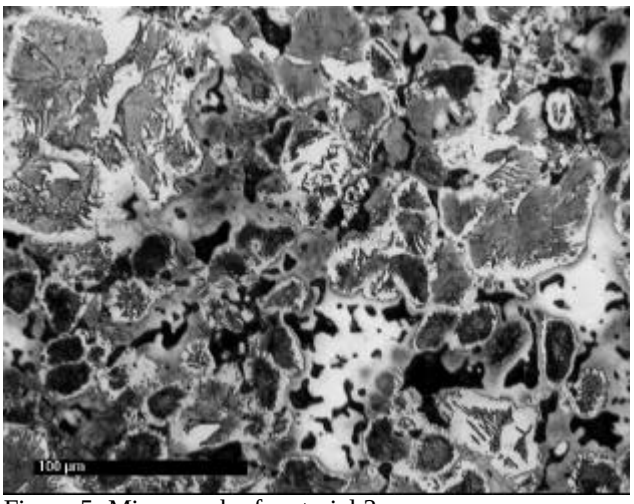


Figure 5: Micrograph of material 3

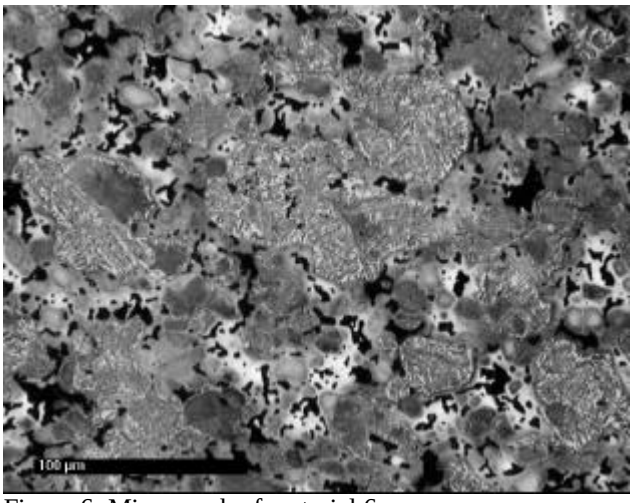


Figure 6: Micrograph of material 6

In figure 3 – 6 the influence on the microstructures can be seen. A typical structure for a diffusion alloyed material is seen in figure 3. The larger original iron powder particles have a perlitic structure with a ferritic edge with some traces of bainite. Surrounding these are areas with martensite. In the martensite also spots of nickel rich austenite is found.

In material 3, see figure 5, non dissolved molybdenum is found in the structure. Also nickel is less well dissolved compared to material 1. The material without any addition of Mo, see figure 4, has less martensite compared to material 1. This is due to the fact that molybdenum stabilizes martensite.

In figure 7 and 8 materials with copper powder of different particle size is compared. The type of copper powder does not have any significant influence on the yield strength but influences the tensile strength. Higher tensile strength is obtained with smaller particle size of the copper powder.

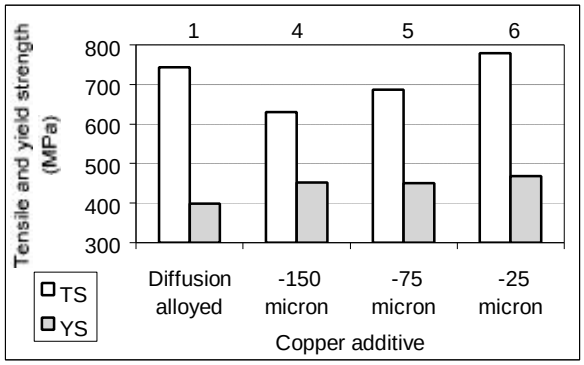


Figure 7. Tensile and yield strength with different Cu additions

Elongation is also improved with finer particle size of copper powder. Even more significant is the effect on the impact energy. Twice the impact energy is obtained when using a copper additive with fine particle size compared to -150 µm copper powder.

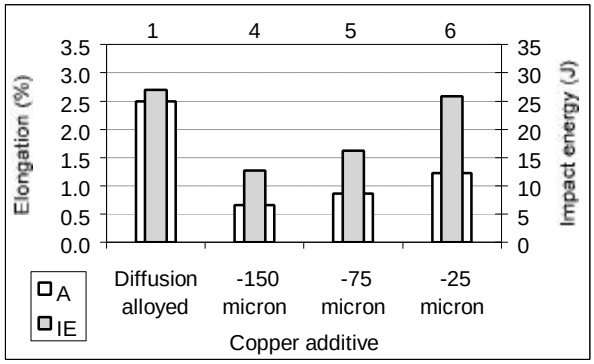


Figure 8. Elongation and impact energy with different Cu additions

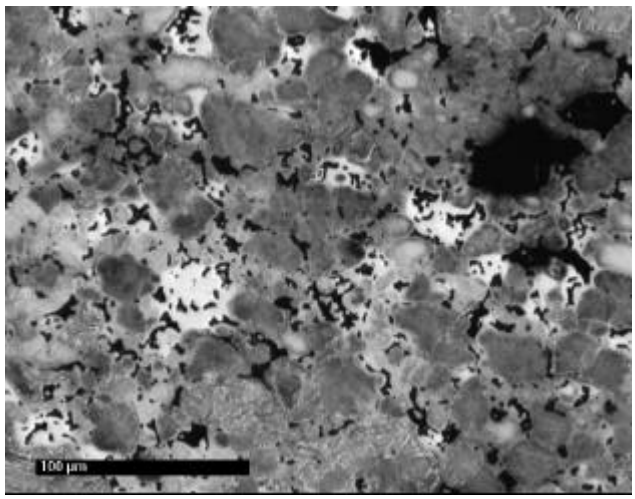


Figure 9: Micrograph of material 4

In the structure of material 6, the center of the larger original iron powder particles is bainitic, see figure 6. As in material 1, they are surrounded by martensite and some spots of austenite. This structure gives very good mechanical properties. If a coarser copper powder is used, large pores can be found in the structure, see figure 9, which is very unfavorable for ductility. Also the

distribution of copper is less good with coarser copper powder.

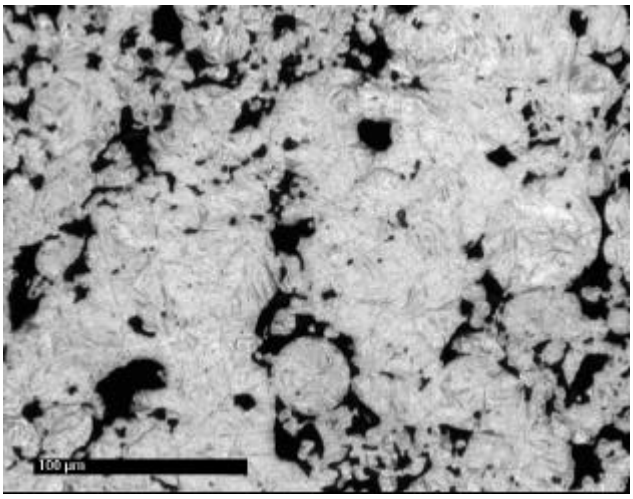


Figure 10:Micrograph of material 7

Material 7 that is pre-alloyed with Cu, Ni and Mo obtains a fully martensitic structure, see figure 10. High hardness is consequently obtained but the ductility is low, see table 3. Mechanical properties beside hardness and yield strength are significantly lower compared to other tested materials. Compressibility is also very low due to the high alloying content.

In figure 11 sensitivity to variations in density, copper, nickel, carbon, sintering temperature and time with respect to dimensional change is presented for material 1. The scale on the y-axis is on dimensional change relative to the dimensional change of a material with the nominal composition and parameters. This is not the absolute level of dimensional change.

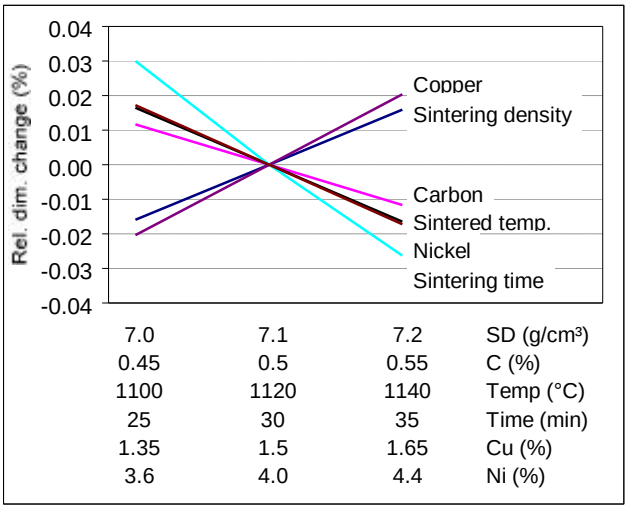


Figure 11: Influence from a number of parameters on dimensional change of material 1

Material 6 was the combination of pre-alloying and organic bonding giving the best mechanical properties. In figure 12 impact on dimensional change from the same parameters and in the same ranges as in figure 11 is presented. It is seen that all lines are somewhat steeper in this graph. With higher sensitivity to these parameters a larger dimensional scatter can be expected. The type of alloying technique does of course also influence the scatter in alloying content obtained in the pressed components. This must also be considered when comparing the dimensional stability of materials. The charts does give an indication of the sensitivity but is not a complete investigation of what dimensional scatter will be obtained with the two types of alloying methods.

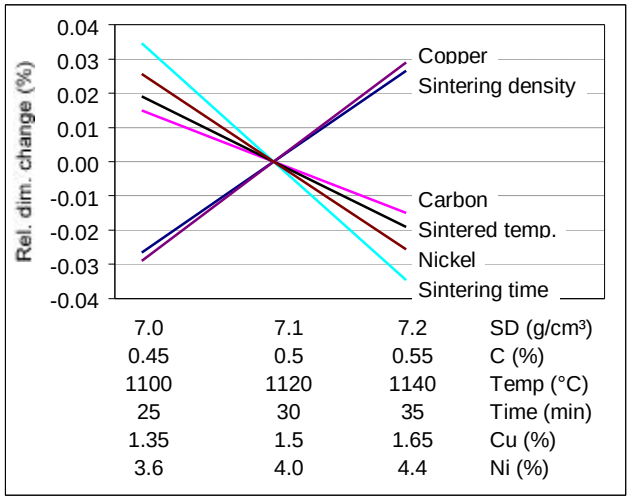


Figure 12: Influence from a number of parameters on dimensional change of material 6

## CONCLUSIONS

By using a combination organic binder and pre-alloyed molybdenum higher yield strength compared to diffusion alloyed material can be obtained with same alloying composition (only Mo is 0.85% instead of 0.5% due to available base powder). Elongation is lower compared to diffusion alloyed material but impact energy is similar.

To admix molybdenum powder gives very little improvement to the mechanical properties compared with pre-alloying or diffusion alloying the same amount of molybdenum.

Particle size of copper powder is important for tensile strength, elongation and particularly for the impact energy. By using copper powder of finer particle size mechanical properties are significantly improved.

The material with pre-alloyed Mo and organic binder for other alloying elements is more sensitive to a number of parameters with respect to dimensional change compared to a diffusion alloyed material.