Performance and Capabilities of Powder Mixes during Warm Compaction

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ABSTRACT

Warm compaction of Densmix™ powder mixes is an established technique to produce PM parts with uniform densities up to 7,4 g/cm³. This has opened new possibilities for cost efficient production of parts with high requirements on both mechanical strength and dimensional tolerances.
This paper will address important properties of Densmix™ powder mixes and how these facilitate efficient and robust production of PM parts. Powder properties at elevated temperature, density levels, lubrication performance and mechanical properties will be described, together with process capability studies from simulation of full-scale production of PM components.

INTRODUCTION

Since its introduction a decade ago as a technique for cost effective production of parts at high densities, warm compaction has steadily gained ground and is now widely used for production of high strength parts [1,2]. Besides the gain in density, higher green strength is also obtained and the lubrication at the die wall is substantially improved. Further benefits have also been explored through combination of warm compaction with other operations such as green machining [3], high temperature sintering, sinter hardening [4], surface densification, etc.

The keys to the stability and performance with this technique are the design of the powder mix, the powder heating system and tooling [5]. Good and robust powder properties at elevated temperatures are a key to a successful production run, and this is possible through the use of engineered lubricants in the mixes, most often in combination with appropriate bonding techniques [6]. This has been explored in Densmix™ powders, which have been especially developed for warm compaction.

Presented at PM2004 in Vienna, Austria, October 2004

Additional benefits from robust powder properties are improvements in parameters such as weight scatter, dimensional scatter and consistency of part shape. The focus of this presentation is to explore the dimensional scatter of Densmix™ powder mixes. Comparing an atomized iron powder with a sponge iron powder will show the influence of base powder quality. Furthermore, the influence of the form of an alloying additive (copper) will be investigated.

EXPERIMENTAL PROCEDURE

Materials

The nominal composition of the mixes was Fe + 2% Cu + 0,6% C + lubricant. Two types of base powders were used: An atomized iron powder (ASC100.29) and a sponge based iron powder (SC100.26). The copper was added either as elemental Cu-200, or as master alloy powder with 10% fine copper which is diffusion bonded to a pure iron: Distaloy ACu (based on atomized iron powder) for the ASC100.29 mixes or Distaloy Cu (based on sponge iron powder) for the SC100.26 mixes. The graphite used was C-UF4 from Kropfmühl. The mixes for cold compaction contained 0,8% lubricant (Amide Wax), while the mixes for warm compaction contained 0,6% lubricant of proprietary composition, specially developed for the Densmix™ process. 500 kg were blended for each of the mixes.

Physical and Mechanical Properties

The powder properties of the mixes were determined using a standard Hall Flow meter equipped with an AD cup. For the Densmix™, both the mixes and the equipment were pre-heated to 120°C prior to the measurements.

Both green and sintered densities, as well as the dimensional change and the mechanical properties, were determined by pressing ring shaped parts (inner/outer diameter 25mm/35 mm, height approximately 13mm) in a mechanical press at a compaction pressure of 700MPa. For the premixes, the die temperature was set to 45°C to simulate steady state production temperatures, while the powder was kept at room temperature. For the Densmix™, both the die and the powder were heated to 120°C before and during the pressing. The parts were subsequently sintered in 90/10 N2/H2-atmosphere for 30 minutes at 1120°C.

Production simulation

In the production simulation for the Densmix™ powder mixes, ring shaped components were pressed in a Dorst TPA45 mechanical press. The compaction pressure was 700MPa, and both the powder and die temperatures were set to 120°C. Nominal dimensions of the rings are diameter 25/35 mm and height 13 mm. For each run, 400 parts were produced and 5 out of every 50 parts were collected for evaluation in terms of weight scatter and dimensional scatter. Full evaluation of the performance was made at 16 strokes/minute, and then the production rate was increased to 20 strokes/minute for a similar evaluation at higher rates.

The collected parts were then sintered for 30 minutes at 1120°C in 90/10 N2/H2-atmosphere and re-evaluated in terms of sintered dimensions and dimensional scatter.

RESULTS

Physical properties
In Table 1, the Hall Flow and Apparent Density are shown for the premixes at room temperature, and for the Densmix™ also at 120°C.

Base Powder	Type	Copper Source	Amount	Hall Flow (s/50g)		AD (g/cm³)	
				25°C	120°C	25°C	120°C
ASC100.29	Densmix™	Cu-200	2%	24,0	23,4	3,17	3,15
	Densmix™	D.ACu	20%	23,7	22,8	3,21	3,23
	Premix	Cu-200	2%	31,6	–	3,07	–
SC100.26	Densmix™	Cu-200	2%	28,2	28,2	2,80	2,75
	Densmix™	D.Cu	20%	28,0	27,2	2,82	2,80
	Premix	Cu-200	2%	37,7	–	2,80	–

Table 1. Powder properties

While the Densmix™ powder mixes exhibit good powder properties compared with premixes, there is still a similar dependence on AD-levels from base powder AD, which is lower for sponge based powders.

Densities and Mechanical Properties
Table 2 shows the influence on the green and sintered densities from the type of mix, base powder and copper powder, and the resulting crushing strength of the sintered components.

Base Powder	Type	Copper Source	Green Density	Ejection Energy	Sintered Density	Sintered Crushing Strength
			(g/cm³)	(J/cm²)	(g/cm³)	(MPa)
ASC100.29	Densmix™	Cu-200	7,29	19,1	7,18	1142
	Densmix™	D.ACu	7,29	17,2	7,18	1080
	Premix	Cu-200	7,16	20,6	7,08	1053
SC100.26	Densmix™	Cu-200	7,19	14,1	7,09	1076
	Densmix™	D.Cu	7,17	14,7	7,09	1027
	Premix	Cu-200	7,03	18,9	6,96	973

Table 2. Densities, lubrication properties and sintered strength

The expected increases in density and mechanical properties from warm compaction are found for both base powder compositions. Compared with cold compaction of premixes, lubrication is also improved using the Densmix™ powder mixes. It is also interesting to note the lower ejection energies for the mixes containing sponge based powder.

Process Capabilities for Warm Compaction

The results given below show the behavior of Densmix™ powder mixes during warm compaction production trials. In Tables 3 and 4, the standard deviations of the weights and dimensions are shown from the measurements at 16 and 20 strokes/minute. The dimensional parameters reported include the outer diameter, ovality (or out-of-roundness) for the outer diameter, the inner diameter, height, and the height variation within each part (max height – min height).

Base Powder	Copper Source	Production rate	Weight	Outer Diameter	Ovality Outer Diameter	Inner Diameter	Height	Height Variation
		(pcs/min)	(g)	(mm)	(mm)	(mm)	(mm)	(mm)
ASC100.29	Cu-200	16	0,04	0,001	0,003	0,002	0,010	0,012
		20	0,05	0,001	0,002	0,002	0,011	0,013
	D.ACu	16	0,05	0,001	0,003	0,002	0,011	0,008
		20	0,05	0,001	0,004	0,002	0,011	0,012
SC100.26	Cu-200	16	0,05	0,002	0,004	0,002	0,012	0,011
		20	0,06	0,001	0,003	0,002	0,013	0,011
	D.Cu	16	0,05	0,001	0,003	0,001	0,012	0,017
		20	0,06	0,001	0,008	0,002	0,014	0,013

Table 3. Standard deviations of weight and dimensions of warm compacted green parts

Base Powder	Copper Source	Production rate	Weight	Outer Diameter	Ovality Outer Diameter	Inner Diameter	Height	Height Variation
		(pcs/min)	(g)	(mm)	(mm)	(mm)	(mm)	(mm)
ASC100.29	Cu-200	16	0,04	0,005	0,018	0,005	0,011	0,014
		20	0,05	0,006	0,020	0,005	0,011	0,015
	D.ACu	16	0,05	0,002	0,005	0,002	0,010	0,006
		20	0,05	0,001	0,004	0,002	0,010	0,011
SC100.26	Cu-200	16	0,05	0,004	0,007	0,004	0,012	0,012
		20	0,06	0,004	0,006	0,005	0,014	0,010
	D.Cu	16	0,05	0,001	0,007	0,002	0,010	0,016
		20	0,06	0,001	0,009	0,001	0,013	0,019

Table 4. Standard deviations of weight and dimensions of warm compacted sintered parts

The effect on dimensional stability is clearly seen from the values for the dimensional changes shown in Table 5. While the scatter for the Spring Back of the outer and inner diameter is very similar for all mixes, the scatter for the green-to-sintered and die-to-sintered dimensional changes for both the inner and outer diameters is clearly connected to the choice of copper source.

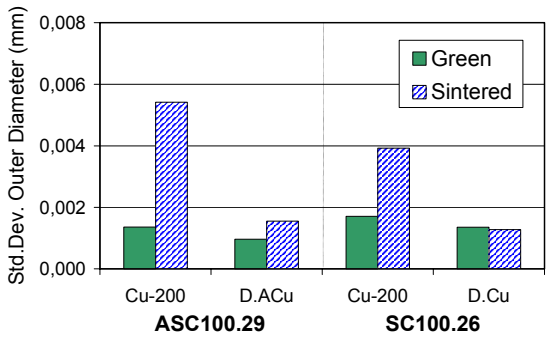
Base Powder	Copper Source	Production rate	Outer Diameter			Inner Diameter			Height
			Spring Back	Green-Sintered Dim. Change	Die-Sintered Dim. Change	Spring Back	Green-Sintered Dim. Change	Die-Sintered Dim. Change	Green-Sintered Dim. Change
		(pcs/min)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
ASC100.29	Cu-200	16	0,005	0,015	0,015	0,008	0,019	0,020	0,014
		20	0,005	0,017	0,018	0,008	0,021	0,022	0,010
	D.ACu	16	0,003	0,007	0,005	0,008	0,011	0,009	0,010
		20	0,005	0,006	0,005	0,006	0,009	0,007	0,018
SC100.26	Cu-200	16	0,006	0,009	0,011	0,010	0,016	0,018	0,014
		20	0,005	0,010	0,012	0,008	0,022	0,019	0,014
	D.Cu	16	0,005	0,006	0,004	0,006	0,011	0,008	0,015
		20	0,006	0,006	0,004	0,014	0,014	0,006	0,014

Table5. Standard deviations of spring back and dimensional changes for warm compacted parts

DISCUSSION

From the measurements of the powder properties, the results indicated that good capabilities should be expected for the Densmix™ powder mixes during the production run. The results presented above showed that an even and consistent performance in the production of green parts was indeed obtained, and that this is maintained on a similar level when production rates are increased from 16 to 20 strokes/minute.

However, despite these consitent values for the dimensions of the green parts, there are still some factors that give differences in the dimensional scatter of sintered parts. To illustrate this more clearly, a collection of key data from pressing at 16 strokes/minute has been plotted in Figures 1A-B and 2A-B. Figure 1A shows the standard deviation for the measured outer diameter of the green and sintered parts. While the figures are very similar for the green state, there is a substantial increase in scatter of the sintered parts for the mixes containing elemental copper. Furthermore, this effect is more pronounced for the atomised base powder than for the sponge powder. This behavior is clearly reflected in the scatter in the die-to-sintered dimensional change, which is shown in Figure 1B.



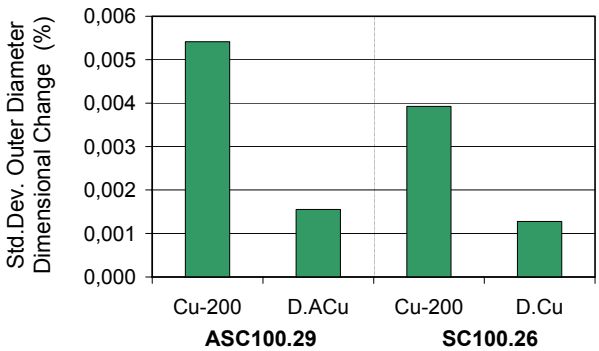


Figure 1, A and B. Scatter of the green and sintered outer diameter (A), and die-to-sintered dimensional change (B) for warm compacted parts

From Figures 2 A and B it can be seen that the parameters that influence the scatter in the outer diameter also influence the quality of the shape of the parts, which tends to become less round

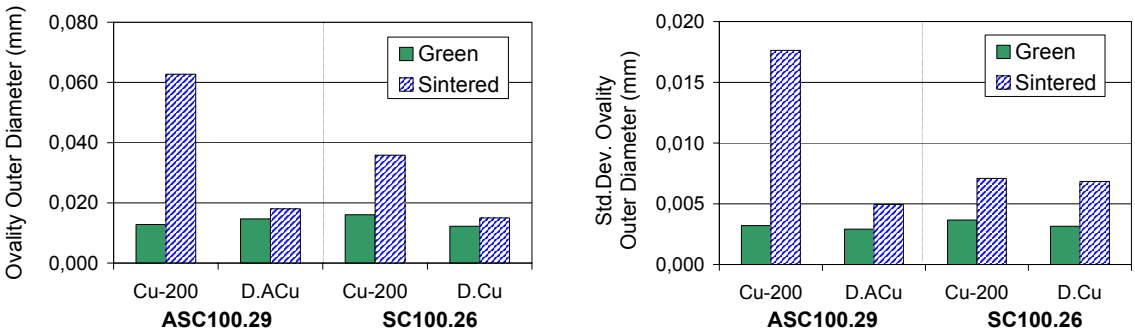


Figure 2, A and B. Averages (A) and scatter (B) of the green and sintered ovality of warm compacted parts

Excellent powder properties in combination with a proper choice of base powders and types of additives can thus provide means to ensure control of dimensional tolerances and part shape consistency during production of PM parts with warm compaction.

CONCLUSIONS

The benefits of increased densities and improved mechanical strength from warm compaction, in combination with the excellent powder properties of Densmix™ powder mixes, provide a path for robust production of high performance parts with close dimensional tolerances.

The choice of base powders has been shown to further influence the dimensional scatter and shape consistency of sintered parts. The sponge iron powder SC100.26 gave somewhat better results than the atomized iron powder ASC100.29. The form of the additives used in the mixes made however a larger impact on these parameters, the diffusion alloyed copper additives giving much better results than the elemental copper additive.

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