EXPERIENCE WITH WARM COMPACTION OF DENSMIX POWDERS IN THE PRODUCTION OF COMPLEX PARTS

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Abstract - Warm compaction of Densmix™ powders provides means to produce PM parts with uniform densities up to 7,4 g/cm^3. As most properties are improved by increased density this compaction technology offers new possibilities of increasing the competitiveness of PM compared to other manufacturing techniques.
In this paper the experience of using warm compaction of Densmix™ powders in production is described. A number of different parts that have been developed during the last years and now are in production will be presented together with material properties and component performances. Process robustness and process capability as well as the benefits that have been experienced with warm compaction are also discussed. The economical advantage of warm compaction compared to other manufacturing methods is also considered.
KEYWORDS: WARM COMPACTION, PRODUCTION, SINTERED MATERIALS, SINTERED PARTS

1. INTRODUCTION

In order to increase the competitiveness of PM compared to other manufacturing processes there is a demand for alloy systems as well as processes that result in improved mechanical properties with maintained tolerances at reduced processing costs. Warm compaction was developed to be one possible technique to meet these objectives. By warm compaction of Densmix™ powders it has become possible to produce PM parts with uniform densities up to 7,4 g/cm^3 by single compaction and sintering and thereby achieve improved mechanical properties.

In this paper the experience of using warm compaction of Densmix™ powders in production is described.

At first some benefits that have been experienced with warm compaction both in laboratory scale and in production are presented. A number of different parts that have been developed during the last years and now in production are then described especially with regard to process robustness and capability. The economical advantage of warm compaction is also considered.

2. WARM COMPACTION PROCESS

The warm compaction process is schematically outlined in figure 1. Characteristic for warm compaction is that both powder and tooling are heated to 130°C (266°F) and 150°C (302°F) respectively [1]. Powders for warm compaction are offered by Höganäs AB, Sweden under the name of Densmix ™. Mixes for warm compaction can be based on any iron and steel powder as well as low alloyed steel powders such as the different Distaloy- and Astaloy grades. The lubricant is optimised to operate at the elevated temperatures at a content of 0,6 %.

Warm compaction was introduced in the market 1994 [1] and has rapidly won ground as a cost effective method to produce high density parts used in various applications. More than 150 different components are in development and production today. The most common parts produced so far are different kinds of gears for hand power tool applications and safety parts for automotive applications. Helical gears for various applications are a fast growing sector for warm compaction.

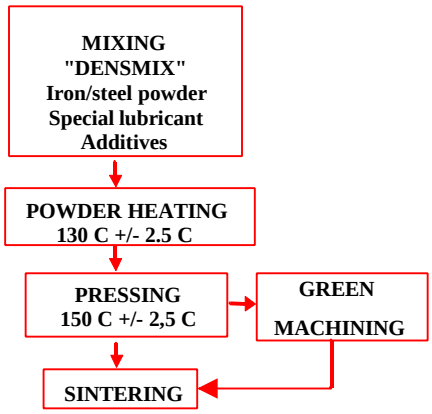


Figure 1: Schematic outline of the warm compaction process

The size of the parts is in the range of 5 to 105 grams in Europe and Asia while in the USA there exists production of automotive parts weighing up to 1100 grams.

The powder heating systems used in Europe and in Asia are the slot heating system developed by Höganäs AB, Sweden. In this heating system the powder is heated by heated oil. The experience shows that the temperature is easily controlled within +/- 1ºC which is well within the recommended +/- 2,5ºC. In USA the heating systems used are the Abbott and Eltemp systems. Typical examples of components that are being produced by warm compaction are shown in figure 2 below [2].

Since the introduction a lot of experience has been gained with warm compaction both in laboratories and in the production of parts. The benefits that have been found

are not only the increase of density, green strength and static mechanical properties but also a number of other advantageous factors that will be important to further increase the competitiveness of PM. In the following some of the merits found with warm compaction will be described in more detail.



Figure 2 Examples of parts produced by warm compaction

3. BENEFITS WITH WARM COMPACTION

Green density

In order to demonstrate the difference that can be obtained with warm compaction in comparison to the conventional PM process at room temperature specimens using both processes have been prepared and evaluated. The powder and processing conditions used are showed in table 1 below. Green and sintered properties were analysed according to standardised test methods.

Table 1. Processing conditions used to compare properties obtained by warm compaction and conventional compaction.

Powder	Distaloy AE
Carbon content, %	0,6
Pressing mode	Cold, Warm
Compacting pressure, MPa	400, 600, 800
Sintering conditions Temperature, ºC / ºF Time, min Atmosphere	 1120 / 2050 30 Endothermic gas

The powder used in the experiments was Distaloy AE which is a diffusion bonded powder containing 4% Ni, 1,5% Cu and 0,5% Mo based on the high compressibility iron powder ASC 100.29.

The obtained green densities for the Distaloy AE based mix at different compaction pressures are shown in figure 3 and table 2. As can be seen the warm compacted Densmix™ powder achieved higher green density than the powder compacted at room temperature at all compaction pressures used. The increase in green density ranged from about 0,30 g/cc at the lower compacting pressure 400 MPa to 0,15 g/cc when compacted at 800 MPa. It can also be seen that the green density of the Densmix™ powder warm compacted at 600 MPa is higher than when compacted at 800 MPa at room temperature.

The densities obtained after sintering are consistent with the green density results shown previously.

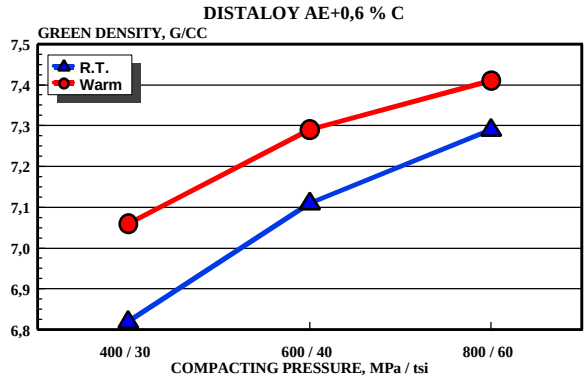


Figure 3. Green density of Distaloy AE after compaction at 150° C and room temperature

Green strength

The green strength achieved after warm compaction is increased about 100 % over the conventionally pressed sample, table 2. The results show a clear benefit for the warm compaction process in comparison to the conventional PM process. The high green strength is a clear advantage which may allow handling of delicate parts also from low green strength base materials without the risk of green part damages. Another option is that machining can be carried out already in the green state and thereby decrease the manufacturing costs.

Table 2. Green and sintered properties obtained with Distaloy AE after compaction and sintering.

Powder	Distaloy AE			
Carbon content, %	0,6			
Compacting mode	Cold		Warm	
Comp. pressure, MPa	600	800	600	800
Green density, g/cm^3	7,11	7,29	7,28	7,42
Green strength, MPa	12	14	28	29
Sintered density, g/cm^3	7,12	7,30	7,29	7,42
Tensile strength, MPa	745	850	845	920
Yield Strength, MPa	389	425	420	452
Impact energy, J	22	38	40	53
Axial fatigue strength, MPa	210		230	

Mechanical properties

The tensile- and yield strength obtained for the differently compacted materials are shown in table 2. In general the tensile strength of the warm compacted material has increased about 10-15 % compared to the conventionally pressed materials using the same compaction pressure. The tensile strength obtained with the Densmix™ based material at 600 MPa compacting pressure is about the same as for the material obtained from the conventional compacted mix using a compaction

pressure of 800 MPa. This increase in tensile properties is related to the increase in density associated with the compaction at elevated temperatures. Regarding other properties like elongation and hardness the results are the same i.e. they increase with increasing density obtained with warm compaction.

The impact energy for the warm compacted Distaloy AE powder achieved a substantially higher impact strength, 40 J compared to 22 J for the conventionally compacted material at 600 MPa. This increase is related to the increase in density and makes this material suitable for applications requiring a good combination of high impact strength and high tensile- and fatigue strength.

Fully reverse axial fatigue tests, at R=-1, on un-notched specimens were also carried out for specimens compacted at 600 MPa. As can be seen from table 1 the warm compacted Distaloy AE material achieved a fatigue strength of 230 MPa which was about 10 % higher than the corresponding cold compacted material. The improvement in fatigue strength is related to the increase in density obtained by warm compaction.

One unexpected benefit that has been found with warm compaction is the finer pore size achieved [3,4]. This results in slightly improved fatigue properties with a decreased scatter.

4. PRODUCTION EXPERIENCE

Helical gear

The density distribution in PM components is always a source of great concern. The warm compaction technology gives the advantage of reaching higher levels of density. To fully utilise these higher levels of density it would also be advantageous if density variations within the component could be reduced. This is especially important for most gears and synchronising parts.

The helical gear, shown in figure 5, combines a complex shape with high demands on strength in the teeth area. This particular gear operates the driving shaft of a hand percussion-drilling machine with a power of 600 Watts. This type of gear has always been a classical PM part but has up to the introduction of warm compaction been manufactured as un-toothed raw parts with a density of about 7,25-7,30 g/cm^3.

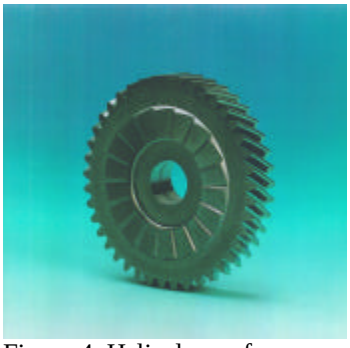
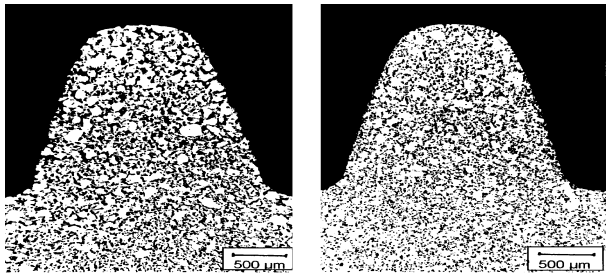


Figure 4. Helical gear for percussion drilling machine

The reasons why it has not been possible to complete the PM manufacturing of ready mountable parts are two. The first one is the expected density loss in the teeth area of the great helical angle of 25º and the other has been the non existence of efficient and controlled tooling systems for compaction of helical gears with a gradient angles superior to 25º.

The manufacturing of this gear was successfully switched to warm compaction a couple of years ago. Thereby it was possible to obtain sufficient density in the teeth area already after single compaction and sintering. Since then more than 500.000 parts have been produced successfully. The powder used is Densmix™ based on Distaloy AB with 0,30 % graphite added. Distaloy AB is a diffusion bonded iron powder with high compressibility containing 1,75 % Ni, 1,5% CU and 0,5 % Mo. The gears are compacted with a compaction pressure of 600 MPa aiming at a density of 7,20-7,25 g/cm^3.



5A 5B

Figure 5: Density distribution in teeth area of helical drilling machine gear. A: Conventional compaction B: Warm compaction

The distribution of density within the gear is shown in figure 5 A and B above. As can be seen the density homogeneity between the core and the teeth area is considerably closer in the warm compacted gear, figure 5B, compared to what is achieved by conventional compaction where the density is much lower and more uneven, figure 5A.

Synchronising ring

Synchronising parts are to a large extent produced by PM already today but still a large number are produced by conventional steels due to strength reasons. As the mechanical properties can be improved by warm compaction due to the increased density a number of more highly stressed parts will be possible to convert to PM. In the following a synchronising ring successfully converted to PM will be described.

The synchronising ring, shown in figure 6 below, has a complex shape with high demands on close tolerances combined with high strength. It is used in a 5 gear rear wheel drive gearbox of a small transport truck. The transferred torque is 270 Nm. It has an outer diameter of 92 mm, an inner diameter of 78 mm and a height of 8,5 mm. As the density after compaction can vary considerably within the part it can be hard to manufacture in mass production scale with good dimensional tolerances. Therefore, production of this complex part utilising the warm compaction process is a good measure of the capability of this technology.



Figure 6. Synchronising ring

The synchronising ring is manufactured by warm compaction followed by high temperature sintering and vibration tumbling. Finally a foil is welded to the ring with the purpose of acting as wear surface.

The ring is warm compacted in Dorst TPA 140 mechanical press to a density of >7,20 g/cm^3 at 6 strokes /minute. The tool is made of high speed steel and equipped with heating device for the die and upper punches. The powder used is Distaloy AE + 0,5 % graphite prepared as a Densmix™ and is heated in a slot heater. The hardness obtained after sintering exceeds 260 HV10 and makes a secondary heat treatment operation unnecessary.

Table 3. Weight scatter of warm compacted synchronising rings

Average weight, g	54,53
Standard deviation	0,040
Maximum weight, g	54,62
Minimum weight, g	54,43
Range, g	0,19
Scatter, %	0,30

By selection of an appropriate material and utilising warm compaction it has now been possible to manufacture this complex component successfully by a cost effective single compaction and sintering process with the required hardness and strength.

Pinion gear

The pinion gears shown in figure 7 below are used in a power tool application.



Figure 7. Pinion gear

The powder composition used for these gears is Distaloy AE admixed with 0,50 % C. The gears are warm compacted in a 45 ton mechanical Dorst press at a production rate of 14 strokes per minute using a compaction pressure of 650 MPa aiming at a density of 7,35 g/cm^3 .

The distribution of density within the hub was also investigated. A density variation of 0,05 - 0,10 g/cm^3 was obtained. A comparative test with conventional compaction at room temperature using the same compaction pressure, 650 MPa, showed a much wider range in density within the part, 0,10 - 0,20 g/cm^3, at a lower overall density, 7,10 g/cm^3.

The weight scatter achieved in continuous production of this gear was found to be less than 0,50 %.

5. CONCLUSIONS

By applying the warm compacting process to low alloy powders such as Distaloy AE it is possible to obtain both static and dynamic properties that before were possible to obtain only by the more costly double pressing and sintering route.

It is also demonstrated that complex parts such as helical gears with helical angles > 25º, pinion gears and highly stressed synchronising rings can be converted to PM from conventional steels. These type of parts are now cost effectively manufactured in mass production in the density range of 7,25-7,35 g/cm3 with good control of both dimensional tolerances and weight as well as with small density variations within the parts.

By utilising warm compaction it is possible both from technical and economical point of view to produce complex parts for new high strength applications which will widen the use of PM in the future.

6. REFERENCES

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