COLD PRESSING POWDER WITH ASSISTED FRICTION COMPACTION FOR HIGH-SPEED TOOL STEELS

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Abstract: Present paper deals with a new technique for compaction of PM parts by use the friction force between pressing die and PM preform as an active force in order to reduce the gradient density on the component length. By moving the container of the die to the punch direction according of a particularly speed, the friction force acts in the same direction as the pressing load with the results of improving pressing condition. The paper presents the experimental results of compaction parameters versus relative speed of die/punch, density distribution and friction force for high-speed tool steels HSS DA 6.

After studying the behavior of HSS DA6 powder in different compacting methods: classical compaction and friction assisted, in both of cases (5.5 g and 8.5 g), higher densities are obtained with the same effective pressure, with assisted friction method.

Keywords: Powder compaction, friction force.

1. INTRODUCTION

Powder Metallurgy is a highly developed method of manufacturing precision metal parts. This enables fabrication of porous and pore-free materials and parts of greatly different shape, dimensions and mass only by consolidating powders in the cold condition and with sintering or additional consolidation, without melting, casting or forming metals.

P/M manufacturing technology consists of three steps: mixing elemental or alloyed powders, compacting those powders in a die at room temperature and then sintering or heating the shape in a controlled atmosphere furnace to bond the particles together. Generally, scrap rates for the process are less than 3 percent [2]. Because the process has so little waste and the part, is often finished when taken from the furnace, the process is very cost effective when compared to manufacturing processes. That must contend with flash, machining chips, and sprues and gates. The speed of the process is such that simple or complex parts can be made to close sizes, often eliminating machining. Production runs range in number from a few hundred to thousands of parts/hour. Conventional P/M parts are limited to parts, which can be formed by uniaxial pressing.

Perhaps P/M's strongest benefit it is ability to eliminate or minimize machining. Tolerances are the key issues here. Following on the minimization of machining, and since the component is shaped in a closed die, there is little or no trim or other process related scrap. These days, close dimensional tolerances, are essential to the reliability and performance of an assembly. P/M's ability to control tolerances is one of the secrets to its successful adoption in the conversion of many components from competing forming technologies. There is essentially no limit to the variety of alloy systems that can be used to produce a shaped component. This gives the designer considerable latitude in matching function and application requirements with a material system to meet those needs such as strength, corrosion resistance or other particular metallurgical or mechanical properties.

2. COLD COMPACTION

The properties of parts produced by compacting powders depend to a great extent on the type and procedure of the compacting press. It is essential to take into account all factors affecting the process and they must be considered when designing the compacting tool or the method of controlling the compacting process from the machine viewpoint. The work carried out by the punch is resisted by a resistance which basically consists of the following forces:

- force for overcoming friction of the powder against the wall of the die (wall friction);
- force for overcoming the friction amongst the individual particles of the powder if they change their position under the effect of pressure (internal friction);
- force for elastic and plastic deformation of the individual particles of the powder and the tool.

At the beginning of consolidation, the friction at the die wall is higher than the other forces. The value of this friction decreases uniformly in the direction to the center of the die. During movement of the powder each particle tries to change its direction of movement under the effect of the pressure acting on it in the direction of least resistance, i.e. in the direction of lowest density. This shows that the powder particles move not only in the compacting direction but also to the center. This results in a non-uniform distribution of density in green compacts as a result of friction.

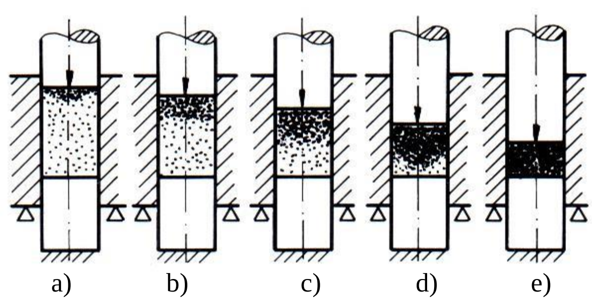

Fig. 1. -Densification under uniaxial effect of pressure.
a, b, c, d, e – different stages of pressing [4].

The highest degree of consolidation and, consequently, the highest effective pressure are recorded at the edges of the upper punch at the die walls, whereas the lowest values are found at the lower edge of the compact. The reduction of density from the upper to the lower edge depends on the height of the compact, the compacting, lateral pressure and the friction coefficient [4].

Classical compaction is done with uniaxial Fig. 1 and double-action compacting procedures Fig. 2. In uniaxial pressing, only the upper punch moves, whereas in double-action pressing, the upper and lower punch or the upper punch and the die move, thus generating relative motion corresponding to double-action compacting.

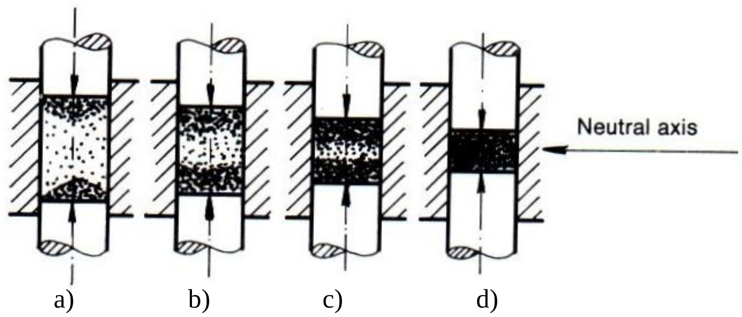

FIG. 2. Densification under double-acting effect of pressure
a, b, c, d– different stages of pressing [4]

The double-acting pressure makes a symmetric distribution of density in relation to the neutral axis. The same density is recorded above and below this neutral axis.

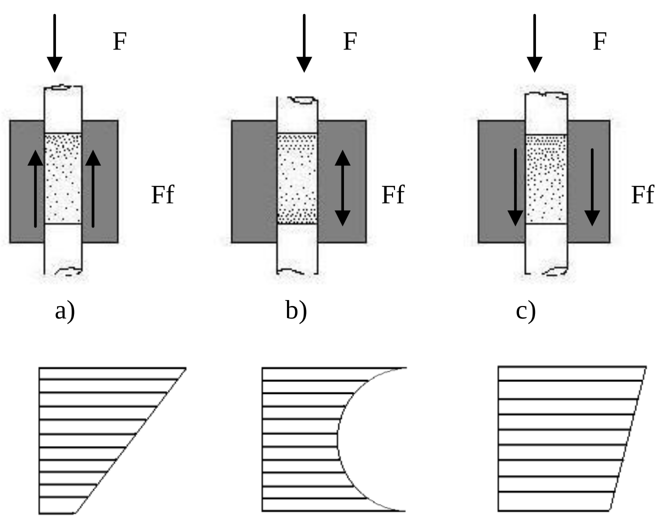

Fig. 3. Different methods of compacting and longitudinal profiles achieved
a) uniaxial method, b) compacting with a floating die, c) assisted friction.

3. FRICTION ASSISTED COMPACTION

Friction between powder and tools plays a major role during cold compaction of PM parts with results on the inhomogeneous densification present work deals with a new method of compaction for PM components by using the friction force between die and compacts as an active pressing force in order to reduce the density gradient. The proposal technique consists in moving the container of the die, during pressing stage to the punch direction according of a particularly speed. As a result, the friction force acts in the same sense as the pressing load with better distribution of powder flow during compaction. The experimental results of compaction parameters versus density have proved the decreasing of the density gradient by increasing container/punch speed rate. A sharp density gradient on the specimen height moving container contrarily to the punch.

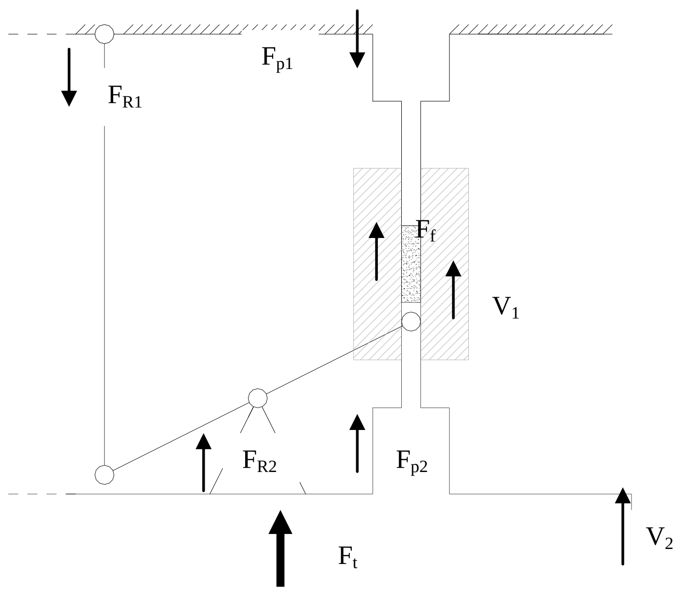

Fig. 4. Assisted friction compaction mechanism [2].

During compaction of the PM components friction between powder and the tool surfaces appears as a great undesirable factor of the process. Inhomogeneous densification across the products length and critical ejection conditions are some of friction results that can produce cracks within the compact and increasing wear on the tools. In order to reduce the friction and to improve compaction conditions several internal lubricants are used (such as zinc stearate, wax or Kenolube). During sintering stage part of the lubricant is removed with the result in decreasing the density by creating new pores. All these limit the performances of the compaction process and the mechanical properties of the parts.

By moving the die to the same direction of the pressing punch with a given speed, the friction force acts as an active load to the flow of powder. The density distribution across the parts depends on the die/punch rate of speed. Even if the friction force cannot be avoided, decreasing it or changing the sense of it is a good benefit for PM industry. The costs for implementing proper devices on the existing press in order to obtain the container movement can be recovered for particular parts.

4. SINTERING

Cylindrical samples have been made of powder HSS DA6 [5]. Sintering is made in a horizontal and tubular furnace. The atmosphere is 100% H_2. First of all, we put argon inside the furnace to clean the atmosphere. After that (when the temperature inside the furnace is about 300ºC), we introduce H_2. A better situation to sinter the samples is using vacuum or a mix of gases (dissociated ammonia), but we have not N_2. Samples were sintered at 1130°C during one hour. Heating and cooling was done according to the sintering diagram, Fig. 5.

Table 1. Sintering conditions

Atmosphere	100% H2
Temperature	1130°C
Time	1 hour
Cooling medium	Inside furnace

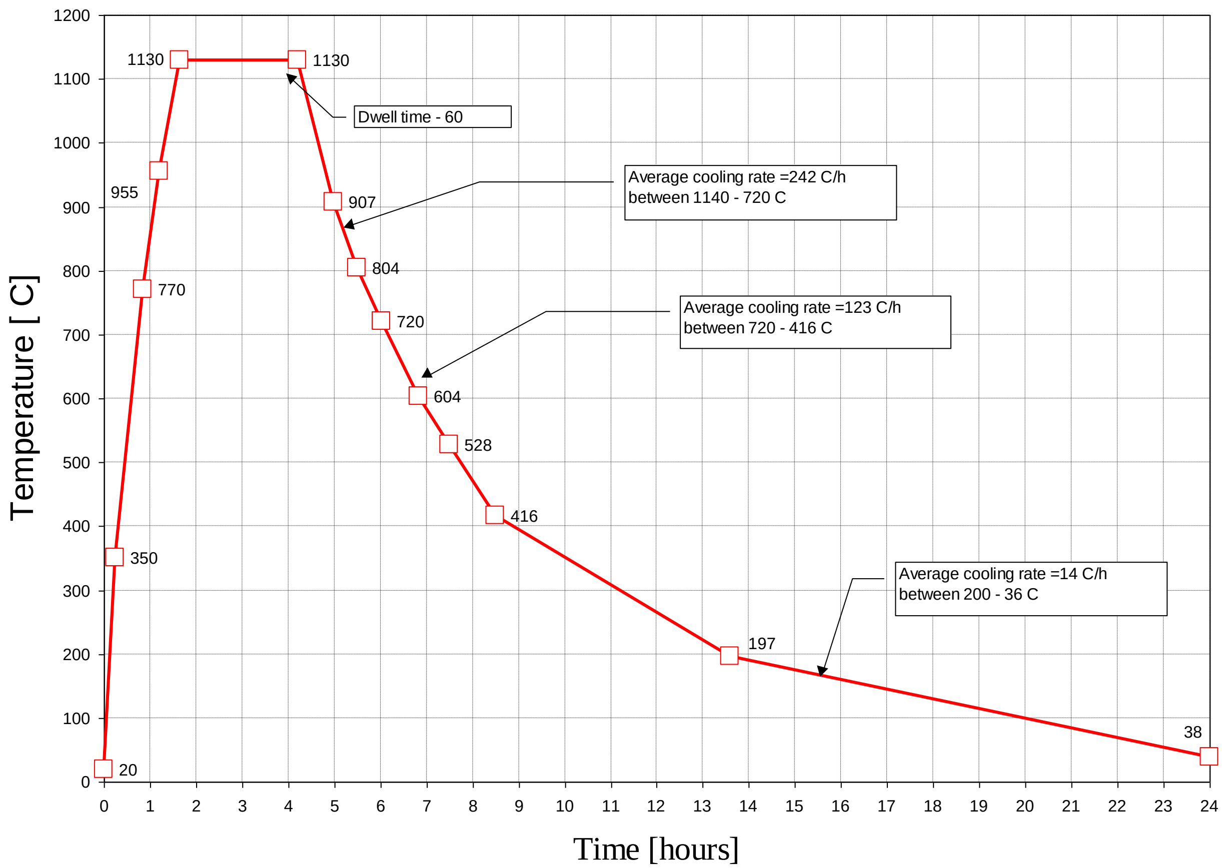

Fig. 5. Sintering diagram, at 1130 ^{0}C [2].

5. GREEN DENSITY

A check of green density is a good verification method at the start of each production run and is checked periodically throughout the run for most of parts. To ensure that the density is relatively homogeneous, the green compact is sectioned and the density of each section was measured.

6. HEAT TREATMENT

Heat treatment is the controlled heating and cooling of metals to alter their physical and mechanical properties without changing the product shape. Heat treatment is associated with increasing the strength of material, but it can be also used to alter certain manufacturability objectives such us improve machining, improve formability or restore ductility after a cold working operation. Thus it is a very enabling manufacturing process that can also improve product performance by increasing desirable characteristics.[1, 3]

For powder HSS DA6 was done quenching and tempering. Samples of first group were quenched and tempered. Quenching was done in one cycle, at 1130°C (heating time: 1.5 hours), maintained for 5 minutes. Then removed from the furnace and cooled in mineral oil. Tempering was made in three cycles, at 520°C, during 2 hours each one. Then removed from the furnace and cooled in air.

Table 2. Heat treatment

Heat Treatment	**Hardening**	**Tempering**
Cycles	1	3
Time	5 minutes	2 hours
Temperature	1130 ºC	520°C
Cool medium	Mineral oil	Air

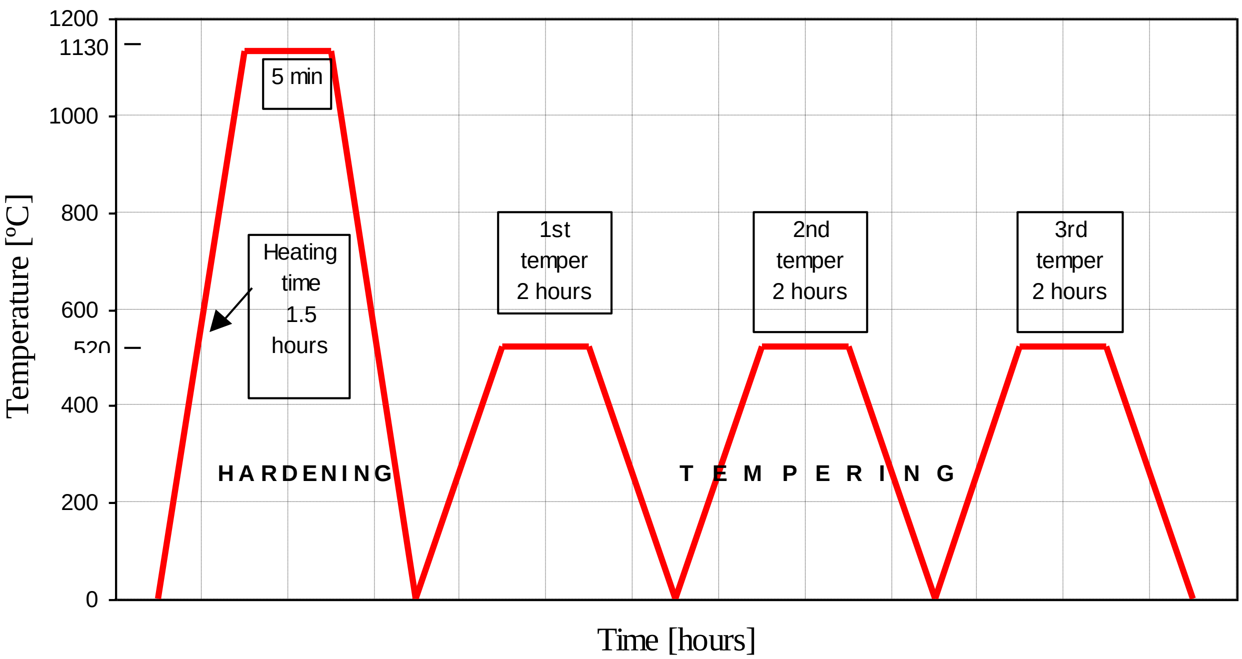

Fig. 6 Cycles of heat treatment [2].

The most interesting results are got in comparison of both methods for the same type of samples. For 5.5 g, average before green density is about 2.5% higher with assisted friction, between 600-800 MPa, while green density for 8.5 g samples is about 2.8% higher with assisted friction, between same ranges of pressures. So, with the same pressure we get higher average density (it means less gradient in each section of the length). Higher density means less gradient and more homogeneous organization of particles. Because of samples with more mass are higher (with same diameter), they have more surface in contact with the walls of the container. During

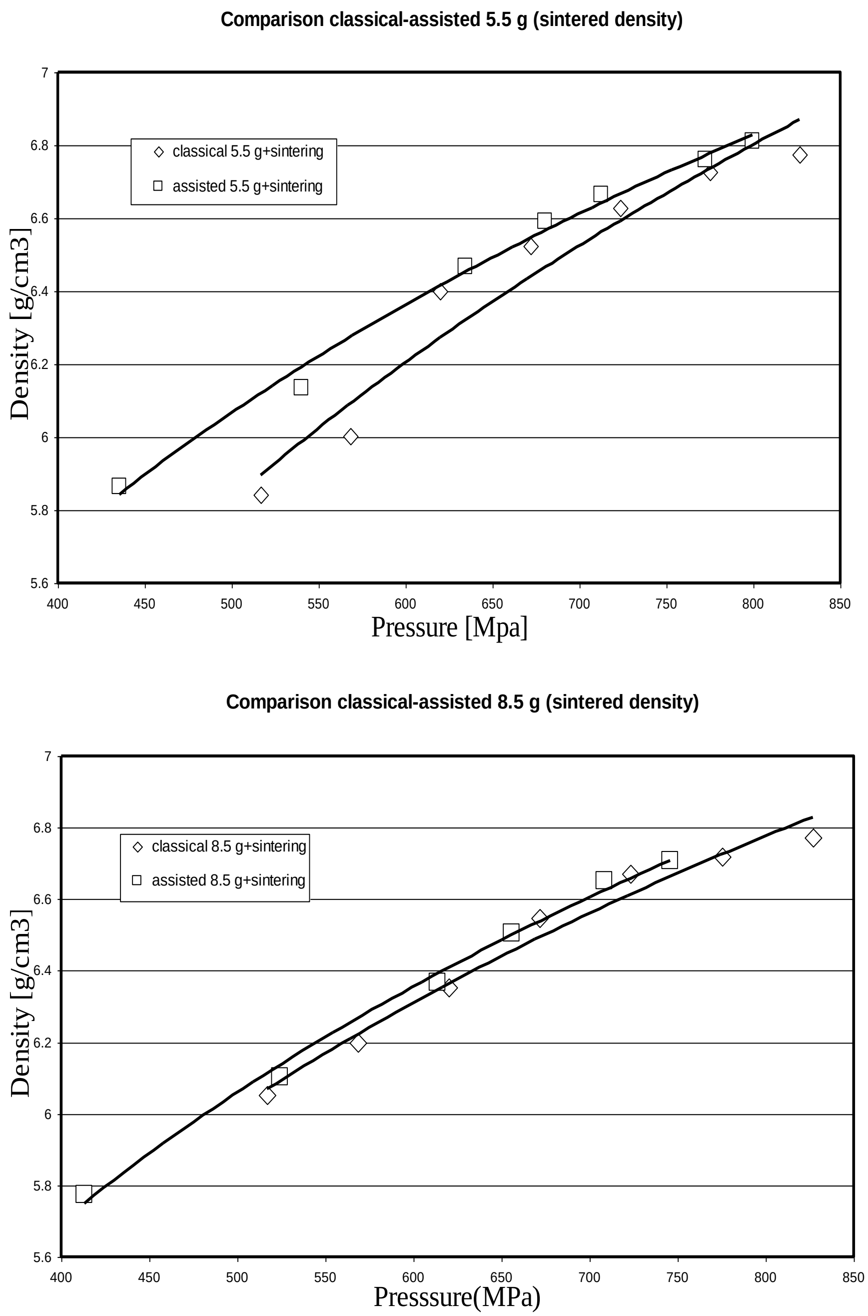

Fig. 7 Sintering density [2].

compacting, friction force between powder and container is more, so the gradient of density is higher for bigger samples, made under the same effective pressure. Or, from another point of view, with the same effective pressure, part of the energy is lost in friction, in classical compaction, so real pressure on powder is less than assisted friction. In assisted friction, friction force acts an active load to the flow of powder.

Anyway, porosity is very high and higher pressures are needed, or increase the amount of lubricant (no recommended).

Graphics after sintering are shown in Fig. 7.

After sintering, general tendencies are the same, but differences between sintered densities are smaller then green densities because of reorganization of particles in classical compaction samples.

Figure shows that samples of 5.5 g achieved higher density than samples of 8.5 g, in classical compaction method (specially noticed in pressures between 500-750 MPa). Higher gradients of density appear again, in bigger samples (because of the bigger surface in contact with the walls of the container.

But most important result is shown in fig 7, where in both cases, higher average densities are got by assisted friction method. Higher densities are obtained with the same effective pressure.

Anyway, the grade of porosity is very high for this type of powder (see micromorphological analysis). Theoretical density (8.1 g/cm^3) is too far away from got densities. We could reduce size of pores by different methods (or by a combination of them):

- Increasing-decreasing the amount of lubricant, to get a compromise between reduction of the degree of wear of the tool (but not too much to avoid large quantities of vapors during sintering, because during sintering stage part of the lubricant is removed with the result in decreasing the density by creating new pores). Or increasing the density of the lubricant.
- Softening particles with different heat treatments, or different annealing conditions.
- Change the chemical composition. The amount and type of alloying elements as well as the annealing treatment of the powder after atomization determine the hardness of the powder. With increasing hardness of powder a given compaction pressure exerts less deformation. Elements like molybdenum and nickel have the smallest detrimental effect, but this powder has no nickel, and the high amount of cobalt helps to increase the hardness of powder.

More advanced methods are used to get higher densities. It is common in industry to size structural parts after sintering to re-establish the geometrical precision that was lost during sintering. To this end the parts are generally plastically reduced in height by about 3-4 % in high precision closed tooling. Since the plastic deformation takes place in a flash less tool set the material attains the radial precision of the die except for the elastic springback of tooling and part. The tool clearances are generally very small and, thus, height reductions translate more or less in an equal density increase.

But, in general, ways to higher densities goes through a compromise among optimum lubricant, geometry and pressure.

Sintering has a governing effect on properties of the samples. The properties change as the PM compact moves from one temperature to another. The under-sinter operation cause low mechanical properties. In the opposite, over-sinter operation cause exagerate growth of grain, and a final and low tenacity and resistance of material.

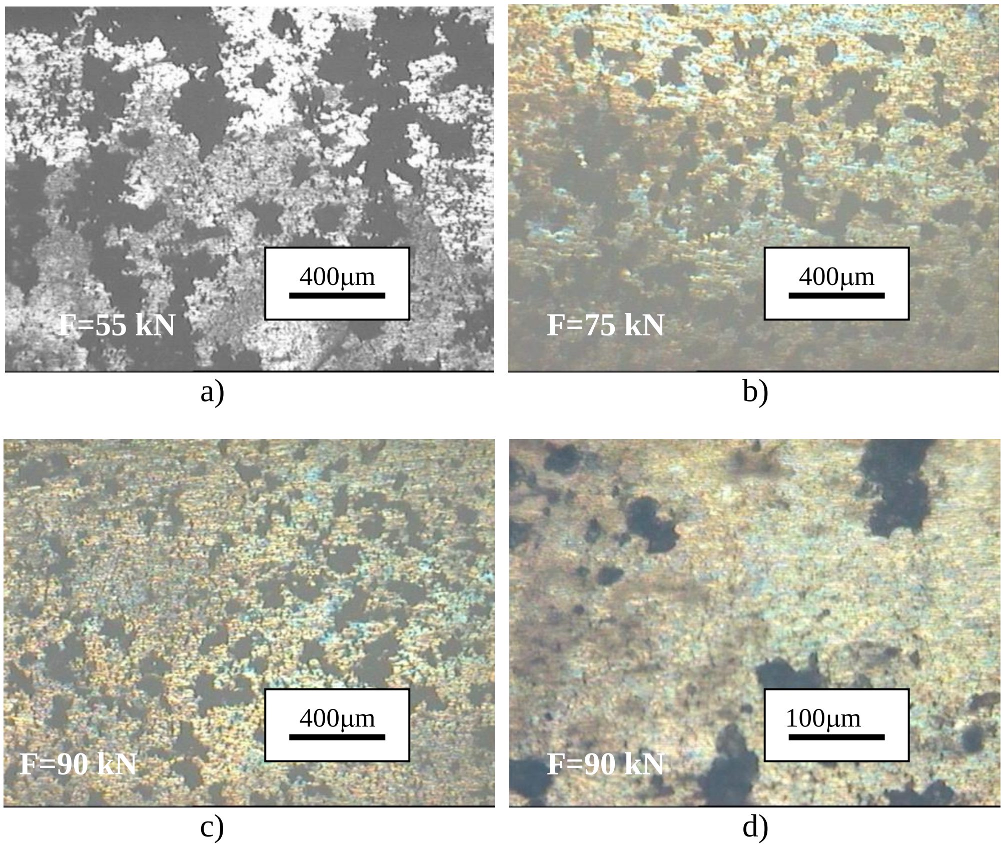

Fig. 8. Assisted friction compaction after sintering
a, b, c, d – microstructure for compaction at different forces.

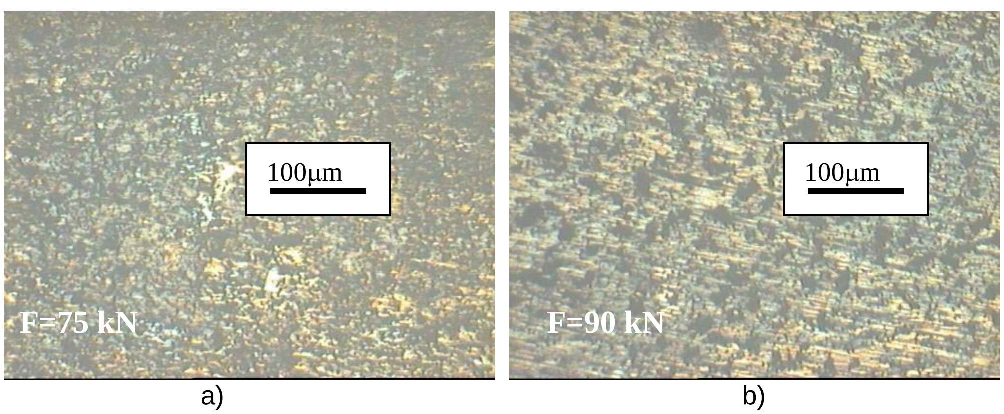

Fig. 9. Assisted friction compaction after heat treatment [2]
a, b, – microstructure for compaction at different forces.

Sintering of the first group, at 1130°C, the samples present and exaggerate quantity of pores, in booth cases, classical compaction and assisted friction. The material is very hard to be compressed. Temperature of sintering was too low for this powder. Microstructure for classical compaction and assisted friction is shown, for different compaction pressures, with an optical microscope IOP, Fig. 8 and Fig. 9.

The porosity and pores in sintered materials are examinate in relation to their properties as a structural component that depends on the properties of sintering powders and conditions of further processing, in this case, heat treatment. Pictures after heat treatment are also shown. The size of pores is very big even after heat treatment. Sintering temperature was too low we could get enough austenite during heating to get, later, martensite.

7. CONCLUSIONS

After studying the behavior of HSS DA6 powder in different compacting methods: classical compaction and friction assisted, the most important conclusions are the following:

- For samples of the same mass, average green density got by assisted friction method is about 0.3% higher.
- For little samples (5.5 g), in comparison with samples for (8.5 g), higher densities are achieved, because during compaction, friction force between powder and container is higher, so gradient of density is higher and average density lower.
- For friction assisted, better and more useful density gradients are achieved, avoiding the undesirable effect of smallest density in the middle section of the sample.
- After sintering, in both of methods (classical and friction assisted), average density increases about 8%.
- After sintering, density for both kind of samples made by friction assisted is closer than made by classical compaction.
- In both of cases (5.5 g and 8.5 g), higher densities are obtained with the same effective pressure, with assisted friction method.
- After heat treatment, friction assisted shows a better distribution of hardness (higher density and reduction of porosity in each section).
- Independently of method used, HSS DA6 particles are very hard and higher pressures are needed in order to achieve closer density to the theoretical.
- Analysis of microstructure shows that the size of carbides is less than 0.1μm, and high porosity; dwell time sintering was not enough large.
- Sintering temperature was not high enough and, because of thermal conductivity, the austeniting temperature should exceed the A_{c3} temperature by 50-80°C, it means closer to 1300°C.

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