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ANALYSIS OF THE PROPERTIES AND CHARACTERISTICS OBTAINED FROM THE PROCESS SINTER FORGING STEEL AISI 4140

André Tavares[1]
Fábio Junkes Corrêa[2]
Luana De Lucca de Costa[3]
Vinicius Matins[4]
Lírio Schaeffer[5]

[1] Mechanical Manufacture *Technologist*. Master degree of Postgraduate Program in Mines, Metallurgy and Materials Engineering (PPGEM). Mechanical Forming Laboratory (LdTM), Federal University of Rio Grande do Sul - UFRGS, Porto Alegre, RS, Brazil. andre.tavares@ufrgs.br
[2] Mechanical Engineer. Master degree of Postgraduate Program in Mines, Metallurgy and Materials Engineering (PPGEM). Mechanical Forming Laboratory (LdTM), Federal University of Rio Grande do Sul - UFRGS, Porto Alegre, RS, Brazil. fabio.correa@ufrgs.br
[3] Mechanical Engineer. Master degree of Postgraduate Program in Mines, Metallurgy and Materials Engineering (PPGEM). Mechanical Forming Laboratory (LdTM), Federal University of Rio Grande do Sul - UFRGS, Porto Alegre, RS, Brazil. luana.lucca@ufrgs.br
[4] Mechanical Manufacture *Technologist and* Professor at the Federal Institute Sul Rio-Grandense IFSul - Campus Sapucaia do Sul. Doctoral degree of Postgraduate Program in Mines, Metallurgy and Materials Engineering (PPGEM). Mechanical Forming Laboratory (LdTM), Federal University of Rio Grande do Sul - UFRGS, Porto Alegre, RS, Brazil. viniciushiper@yahoo.com
[5] Professor Dr.-Ing. Coordinator of Mechanical Forming Laboratory (LdTM), Federal University of Rio Grande do Sul - UFRGS. Fwd: Bento Gonçalves, 9500. CEP: 91501-970, Porto Alegre, RS, Brazil. schaefer@ufrgs.br

Abstract

This work is a study on the sinter forging technological aspects, where changes are made in the temperature and strain parameters. Experiments were performed to study the microstructural variations and properties such as hardness and densification, and also which variations in the force used to obtain the strain established. The relationship between the shear stress at the interface and other process variables is discussed. An analysis is made to calculate the pressure distribution and load from balancing equations. The results are discussed and processing parameters involved during the sinter forging process are analyzed.

keywords: Metal powders forging, sinter forging, AISI 4140 steel and powder metallurgy.

1 INTRODUCTION

Preforms obtained by sintering of metal powders compressed have being used in forging processes and represent an economical method for the production of high densification parts and improvement in the mechanical properties. This technology allows the metal powder compacted and sintered is used as a preform to form forged parts with dimensions larger than those obtained from the preforms deriving other manufacturing processes, besides, better mechanical and metallurgical properties due to homogeneity distribution of the grains. The production cycle of parts sinterforjadas is represented schematically in Figure 1 [1, 2].

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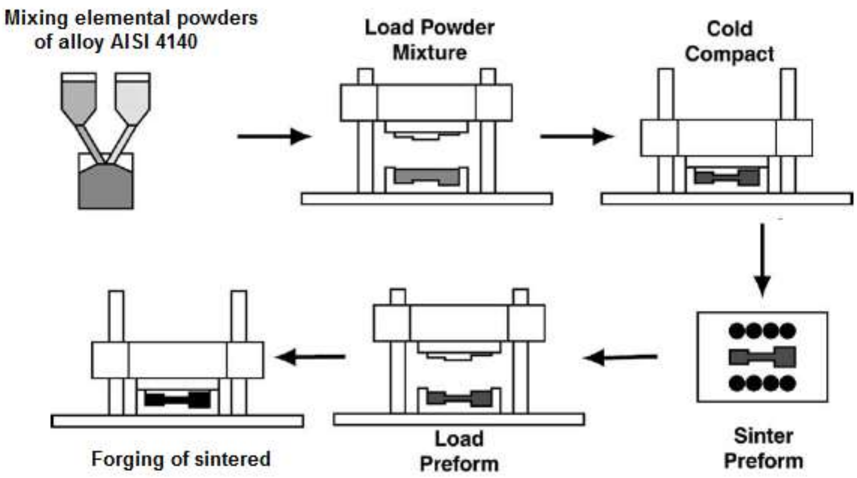

Figure 1 – Sinter forging schematic cycle.

The deformation pattern during the forging of sintered bodies is different compared to the conventional, therefore, the characteristics of the porous material undergoing deformation have fundamental importance, because the elimination of pores initiated in the begin of the plastic deformation causes a change of density, as shown in Figure 2. Another important characteristic is that the components obtained by sintering metal powder have low hydrostatic stress different of the billets and preforms obtained by other manufacturing processes [3, 4].

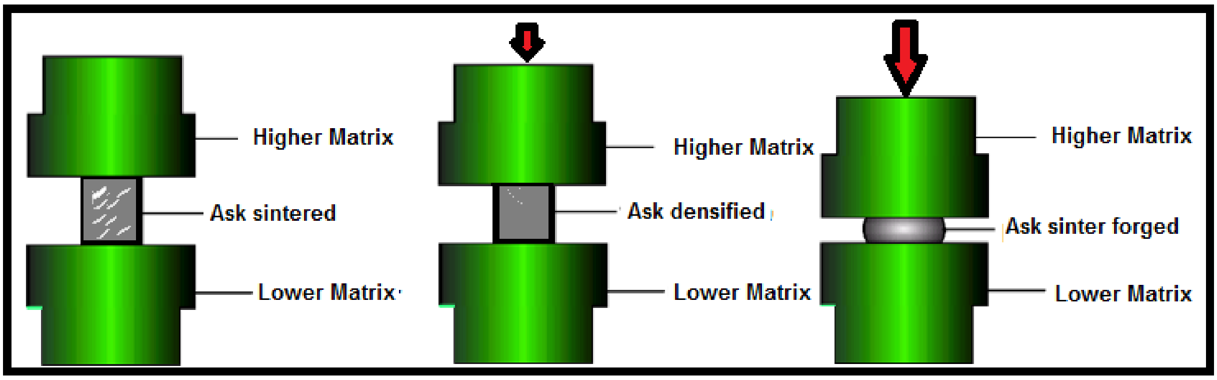

Figure 2 – Simplified steps of sinter forging in open die.

The main factors in the sinter forging process are the density of the preform, the lubrication conditions at the interface piece/die, the flow stress in the sintered body and those related to the equipment such as strain, strain rate and applied load [5]. The predetermination of the appearance defects in the products obtained by this process requires an understanding of the deformation mechanism and pressure distribution at the interface of sintered material, together with differences in the distribution of residual stress and porosity in order to ensure that the workpiece obtains superior properties after forged [5,6].

Several studies have been reported recently and cover various technological aspects of industrial processing of sintered products, however, they are still in attempts phases to predict the mechanical properties of the sintered materials, there

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being not solution to systematic prediction of the dynamic effects during the sinter forging due to high speed in the process [2,4].

In recent years the interest in the work high speed has grown considerably due to the need of production to meet market demand, therefore, the introduction of new and fast forming techniques are becoming indispensable and making researches of the inertia forces effect during sinter forging to enable process high speed. [5,7].

This study aims to study the dynamic effects, microstructure and hardness from different reductions in sinter forging at high speed. Specimens steel AISI 4140 obtained by powder metallurgy were prepared and forged at ambient temperature and at 1200° C. It was performed microscopic analyses of variations in the longitudinal and transversal microstructure verifying the densification during the process.

The relationship between the shear stress at the interface and other variables are analyzed together with the pressure distribution calculation. The equilibrium equations solutions take into account the bulging for the axial symmetry to the sinter forging plane strain. The results are discussed critically to illustrate the interaction of processing parameters during the process that are presented. It is expected that this paper has practical relevance and importance in the design of equipment and tools necessary to provide high speed the process of sinter forging.

2 MATERIAL AND METHODS

In the present study were evaluated AISI 4140 steel specimens derived from rolling process and from powder metallurgy by mixing elemental powders with dimensions of 13mm diameter and approximately 20mm height. They were subjected to compression testing analogous to open die forging process.

For AISI 4140 steel elemental powders compaction was performed mixing elements in the percentages shown in Table 1. Using a precision balance, the percentages were measured for the mixture, resulting in 300g bulk to make the mixture being used the double cone rotary mixer for thirty minutes at 22 rpm. It added 1,5% of paraffin to the total weight for the mixture to obtain higher green strength of the compacted specimens. This mixture was gently heated to melt the paraffin and homogenization of the mass.

Table 1- Chemical composition of AISI 4140 steel from elemental powders.

C	Si	Mn	Mo	Cr	Fe
0,40%	0,25%	0,88%	0,2%	0,95%	97,325%
0,12 g	0,75 g	2,85 g	0,6 g	2,85 g	291,98 g

The compaction pressures showed densification results in function of pressure exerted. The mixture was weighed and fractionated into ten equal parts which were compacted in a uniaxial cylindrical die with a diameter of 13,0mm, compression applied with pressures ranging between 100 and 1000 MPa. The samples were compacted and their masses measured to calculate the green densities which enabled the construction of the compressibility curve of specimens for selection of compaction pressures ideal to the experiment conditions. The results showed compaction pressures of densification as a function of pressure.

The sintering occurred in temperature 1150 °C and the heating rate 10 °C/min, maintained at level heat for sixty minutes and cooled in the furnace, as the curve

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shown in Figure 3. The sintering atmosphere was composed of 25% hydrogen and 75% nitrogen and kept until to full cooling in ambient temperature of the specimens.

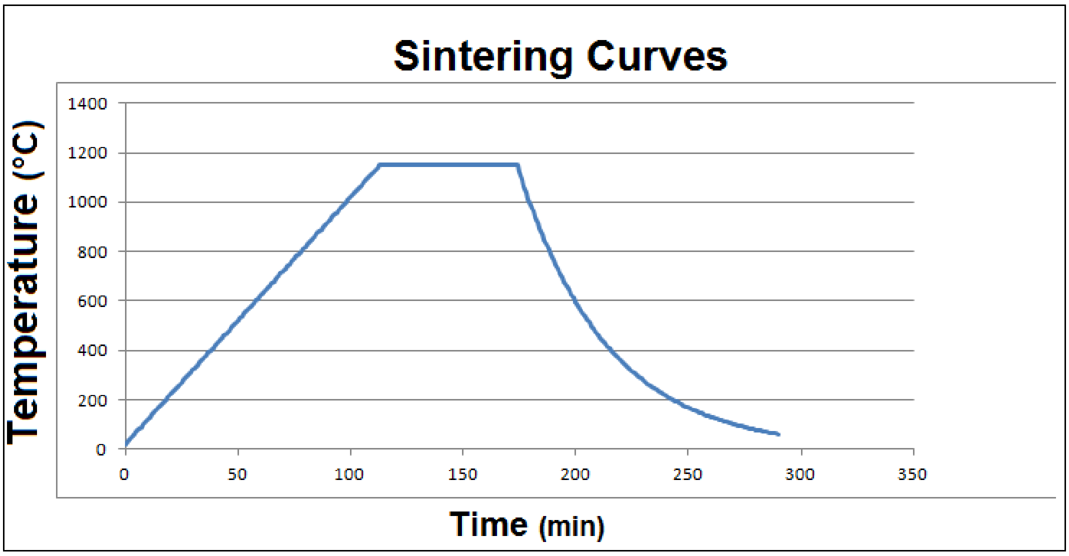

Figure 3 – Sintering curve used to SAE 4140 steel.

The microstructural morphology of the sintered specimens were revealed from samples previously polished and using chemical etching with Nital to reveal the grain boundaries and analyzed using optical microscopy.

To evaluate the process was compacted five bodies sinter forged with pressure of 700 MPa and sintered. After this, the samples were subjected to the compression test, with reductions in height of 20 and 30%, hot and cold. Considering for mild steels and soft steel, the time for homogeneous heating is one hour per inch [3], so the bodies to be forged were heated for 15 minutes before compression test.

The specimens with mass of approximately 20g and pressure of 700 MPa have conditions suitable for use in testing sinter forging due to dimensional be easy to handle. The results are shown in Table 4 and Figure 4.

Compression tests were conducted on specimens resulting from the rolling process using the same reduction for obtaining the flow curve in order to compare process variables. The faces of all specimens were sanded to reduce the interfacial friction between them and the dies. Through a hydraulic press with the 40 tonf capacity was executed compression of the specimens and with the use of a universal caliper was possible to measure the dimensions of the specimens before and after the test. To control the instantaneous efforts and displacements were used linear displacement sensor and a load cell. These data are handled by Catman program from the data acquisition system HBM, which makes the transfer of the values obtained in the testing.

3 DISCUSSIONS AND RESULTS

From the prepared mixes with elemental powders and to determine the compaction pressure appropriate it was drawn compressibility curve. The table 2 presents the data having a variation 100 to 1000MPa.

Table 2 – Data for compressibility curve of AISI 4140 steel.

Pressure (MPa)	Diameter (mm)	Height (mm)	Volume (mm³)	Mass (g)	Density (g/cm³)

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0					4,5
100	13.01	7,50	0,997	4,993	5,01
200	13.04	6,73	0,899	5,004	5,57
300	13.03	6,33	0,844	5,007	5,93
400	13.01	6,03	0,802	5,009	6,25
500	13.02	5,97	0,795	5,026	6,32
600	13.01	5,85	0,775	4,999	6,45
700	13.01	5,72	0,760	5,005	6,58
800	13.03	5,76	0,768	5,000	6,51
900	13.04	5,86	0,783	4,997	6,39
1000	13.02	5,48	0,730	4,686	6,42

With the data obtained was drawn compressibility curve as shown the Figure 4.

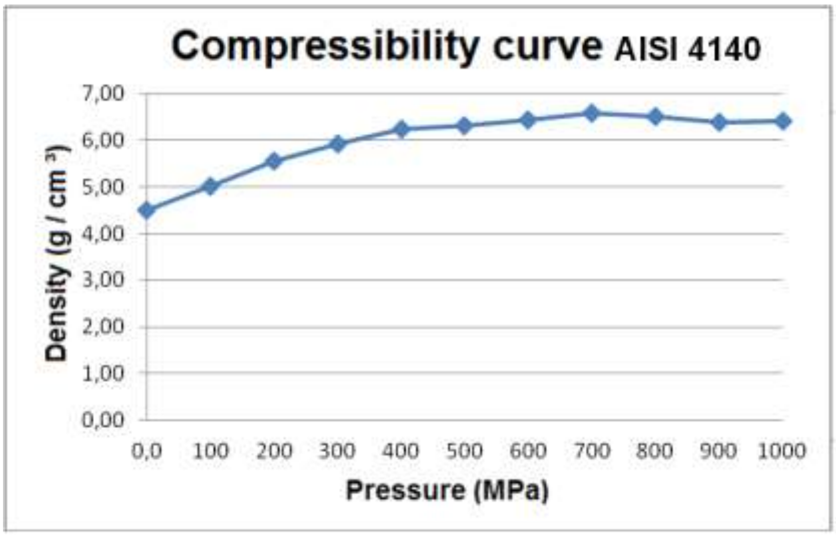

Figure 4 – Compressibility curve of samples SAE 4140 steel.

The samples were sintered at 1150 °C and the results are shown in Table 3.

Table 3 – Data for the compressibility curve SAE 4140 steel synthesized.

Pressure (MPa)	Mass (g)	Volume (cm^3)	Density of the sintered (g/cm^3)
100	4,92	0,77	6,39
200	4,98	0,76	6,55
300	4,97	0,75	6,63
400	4,95	0,73	6,78
500	4,97	0,74	6,72
600	4,95	0,72	6,88
700	4,97	0,72	6,90
800	4,96	0,73	6,79
900	4,95	0,72	6,88
1000	4,65	0,68	6,84

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From the data to the curve compressibility for the synthesized SAE 4140 steel, Table 3, it was possible to obtain the densification curve of the sintered samples as shows the Figure 5.

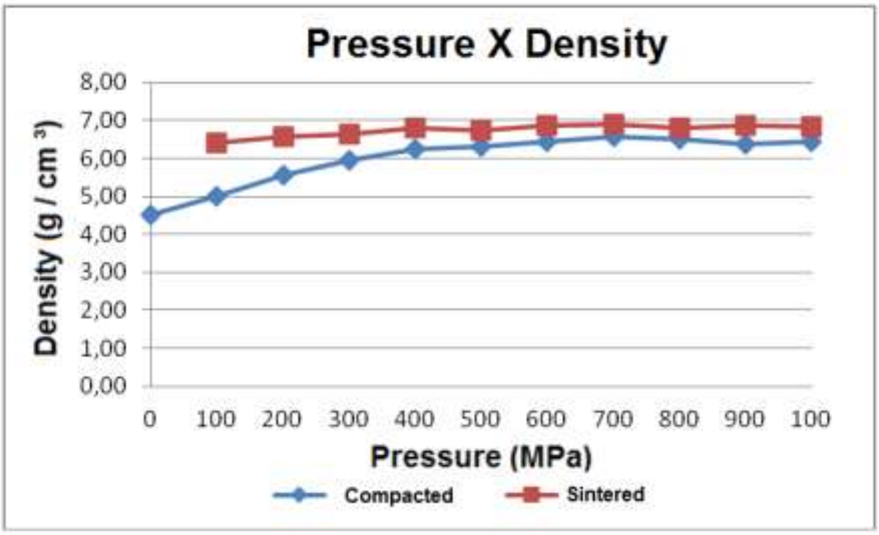

Figure 5 – Densification curve of the sintered SAE 4140 steel samples.

To evaluate the sintered samples mechanical characteristics, it were analyzed properties of hardness and microhardness dividing the samples into two groups. Parts compacted with 100MPa, 500MPa and 1000MPa were analyzed the Vickers hardness (HV), while the samples with 200 MPa, 600MPa and 900MPa were used to analyze the Rockwell B hardness (HRB).

The microhardness data are shown in Figure 6 where there is a tendency increasing after the pressure of 500MPa and reduction the pressure of 1000MPa, five measurements were performed each sample. It is noted that the microhardness values are very low and there isn't significant difference between them.

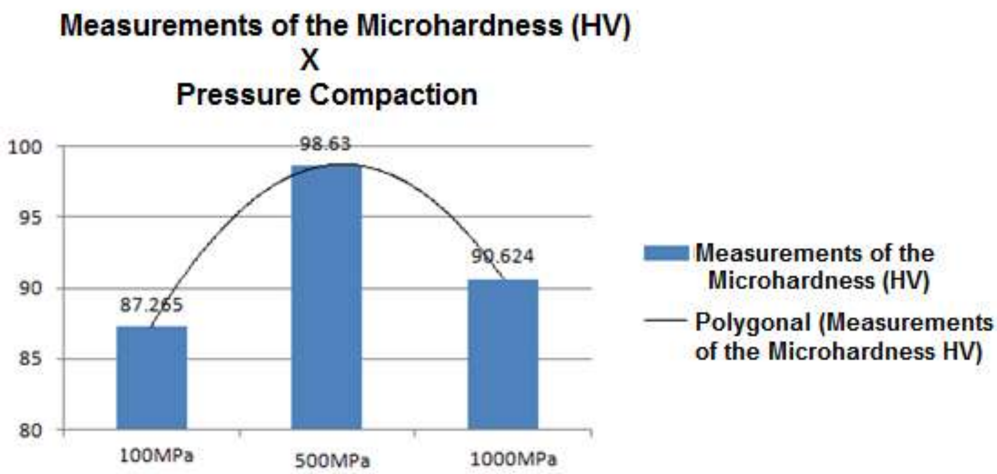

Figure 6 – Analysis of microhardness of the SAE 4140 sintered steel samples.

In Figure 7 can see a clear growth trend between samples analyzed and determine the optimal point for the mechanical properties is between the range of 600 and 900 MPa.

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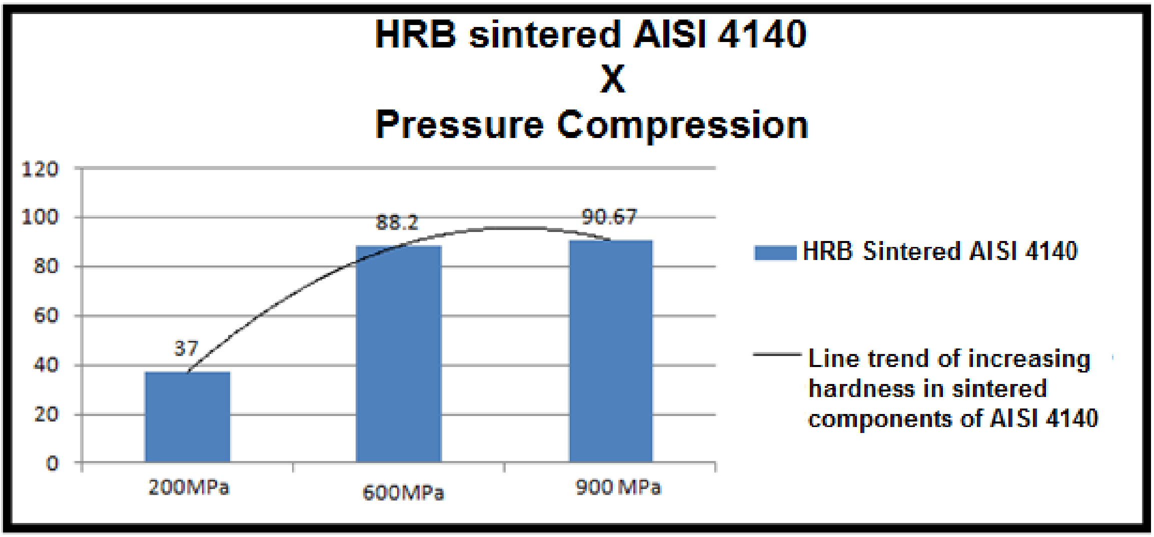

Figure 7 – Analysis of hardness of the SAE 4140 sintered steel samples.

The analysis of the results shows that the mass of 20g and pressure of 700 MPa are the best conditions to be used in the sinter forging. Table 4 presents the results of the specimens tested.

Table 4 – Data of AISI 4140 steel obtained by mixing elemental powders.

Sample	Diameter (mm)	Height (mm)	Mass (g)	Volume (mm³)	Density (g/cm³)
1	13,1	19,5	19,09	2791,12	6,83
2	13,1	20,05	19,55	2869,84	6,81
3	13,1	20,25	19,85	2898,47	6,84
4	13,1	20,35	19,86	2912,78	6,81
5	13,1	20,35	19,90	2912,78	6,83

The samples were sintered and then forged under the conditions of 20 and 30% reductions, both the ambient temperature as the heated to 1000 °C, the samples ratio and their micro hardness are shown in Table 5.

Table 5 – Data of conventional forging processes and sinter forging.

Sample	Process for Obtaining	Reduction (%)	Temperature Forging	Microhardness Measurements (HV)	Density Previous (g/cm³)	Density (g/cm³)
1	Laminated	0	Ambient	263,35	7,82	7,82
2	Laminated	20	1000°C	270,28	7,81	7,73
3	Laminated	30	1000°C	580,64	7,82	7,62
4	Sintered	0	Ambient	121,51	6,83	6,81
5	Sintered	20	Ambient	181,51	6,81	6,96
6	Sintered	30	Ambient	181,10	6,84	7,08
7	Sintered	20	1000°C	222,82	6,81	7,05
8	Sintered	30	1000°C	670,00	6,83	7,05

Such as initial parameter were measured the hardness to the sintered sample and to the rolled sample. The sintered sample has higher hardness than the compressibility curve preliminary samples. But this micro hardness is half the rolled

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sample and evolved little during cold compression, however occurred an increased density.

The curve describe true stress as a function of true strain of rolled material, as shown in Figures 8.

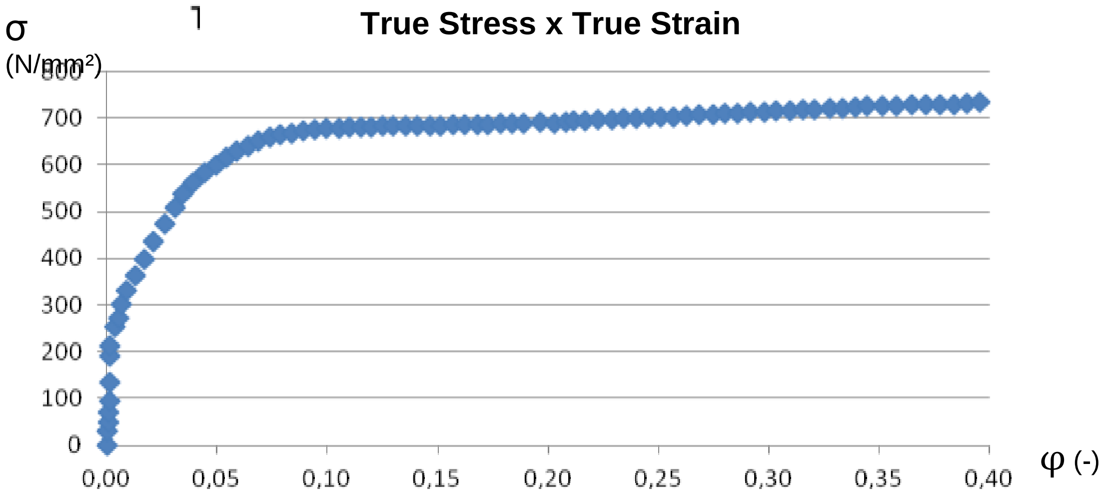

Figure 8 – True stress in function of true strain for the cold compression test for the rolled material.

Figure 9 shows the curve that describes the true stress as a function of true strain of the sintered material for the cold compressed metal powders specimens.

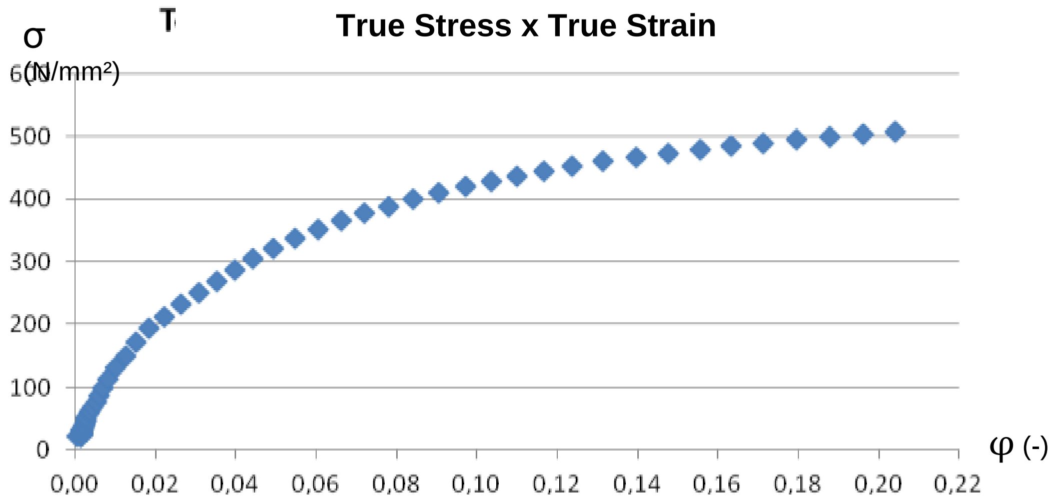

Figure 9 – True stress in function of true strain for the cold compression test for the compacted and sintered material.

The Figure 10 shows the curve that describes the true stress as a function of true strain of the sintered material for the hot compressed metal powder specimens.

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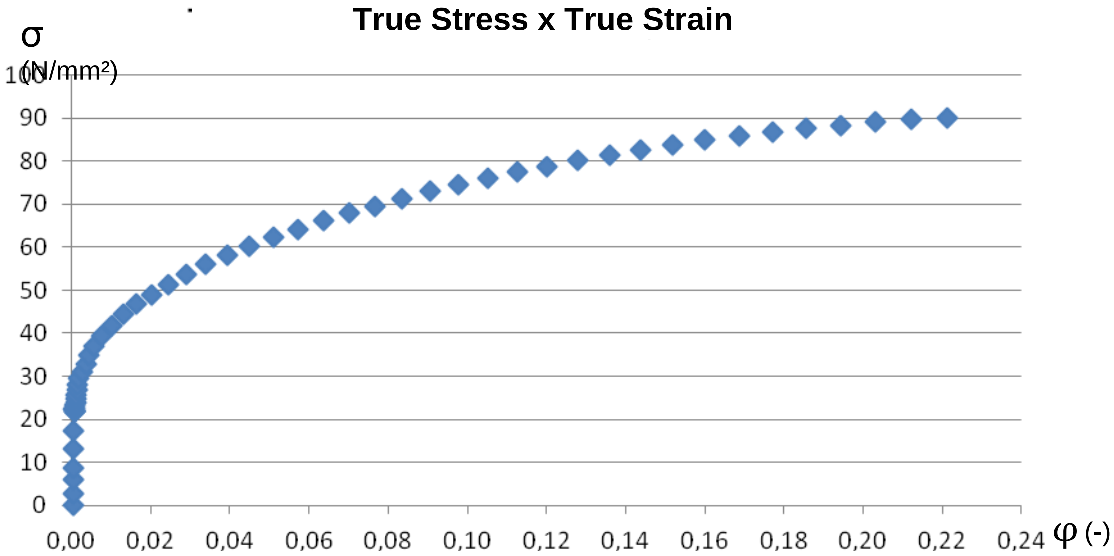

Figure 10 – True stress in function of true strain for the hot compression test for compacted / sintered material.

Analyzing the true curves of the compression test, it was noted that needs higher stress to promote the deformation of the rolled material than sintered. And the rolled sample get greater true strain. This resistance is the fact that the same has aligned grains during the previous preceding to the test. Another important fact is that the sintered material and hot conformed increased density, but needed only one fifth compressions stress of cold forming material. The table 6 shows the results comparison of stress obtained in the compression testing for the three conditions performing.

Table 6 – Stress values in function of the true strain.

	Cold test of the rolled sample	Cold test of the compacted / sintered sample	Hot test of the compacted / sintered sample
Stress	720 N/mm²	500 N/mm²	90 N/mm²
Strain	0,44	0,20	0,22

For all sintered samples and then forged, densification has occurred. The forging process the sintered promotes initially the closure of pores, after this process begins the forging itself, where starts the sliding of the planes. When analyzed the metalografias can notice the reduction of pores, either by closing or flattening, shown in Figure 9, being that the Figure 11 A is the sintered sample 4 and the Figure 9B is the sintered sample 5 with a 20% reduction during forging. It is noted that the sintered sample has larger pores than sample sinter forged.

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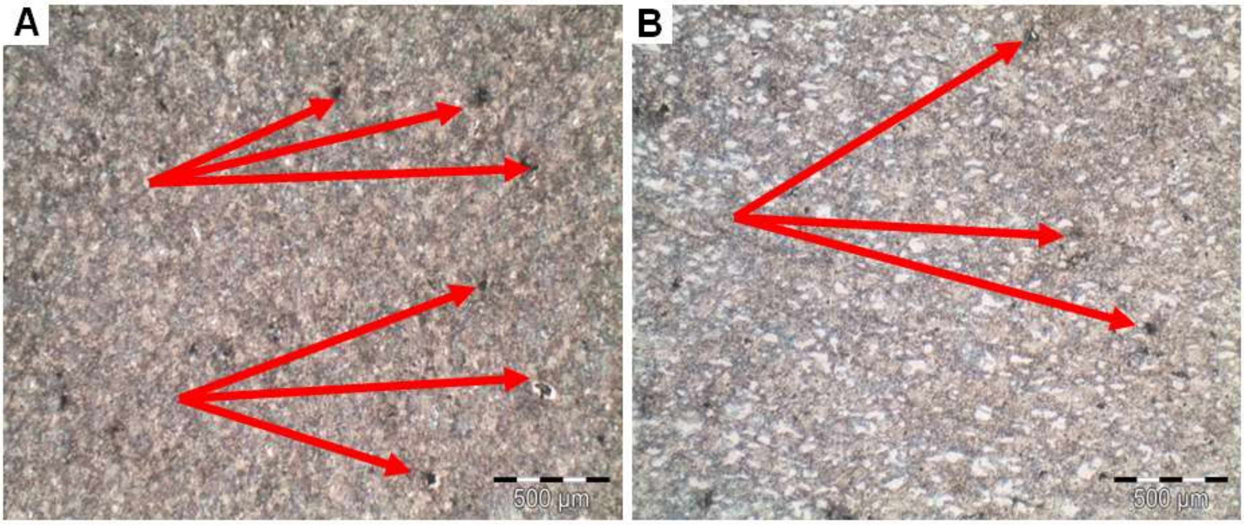

Figure 11 – Analysis of the reduced porosity of the sintered samples and comparative sinter forged.

Figure 12 shows the metallographic of sinter forged samples, being that the Figure 12.A shows the cold forged sample 6 after the sintering with 30% reduction and Figure 12.B shows the hot forged sample 7 with 20% reduction.

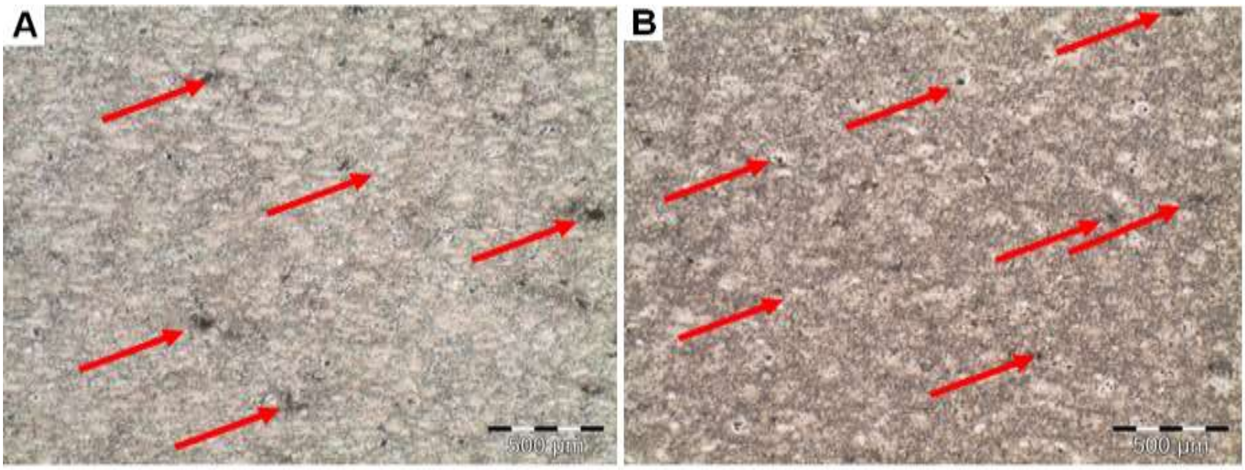

Figure 12 – Cold sinter forged of the sample 6 and e hot sinter forged of the sample 7.

It is observed that in Figures 12.A and 12.B there was a porosity reduction of the sintered samples. The cold forged sample has larger pores than hot forged sample with 20% reduction. The pores from hot reduction are much smaller and fewer amount than the cold forging, showing that the hot process is the best indicated. Performing a discussion of the data from Table 5 and 6 with the Figures 68to 10, it is noted that the rolled samples had higher densities and decreased during the hot forging due to its oxidation. The sintered parts density increased with the forging that was expected and suffered the same oxidation influences.

The hardness increased with the samples forging indifferent of the parts manufacturing process before forging, and then, indicating that the temperature associated with a higher reduction rate causes increase of micro hardness. The best result found was the sintered and forged sample with 30% reduction in height. The cold rolled samples showed a stress near 700 N / mm² against the value near 450 N / mm ² of the sintered sample. Figure 13.A shows the rolled sample 1 without forming,

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showing the bar initial structural used. Figure 13B shows the laminated sample 2 with 20% reduction in height by forming to 1000° C.

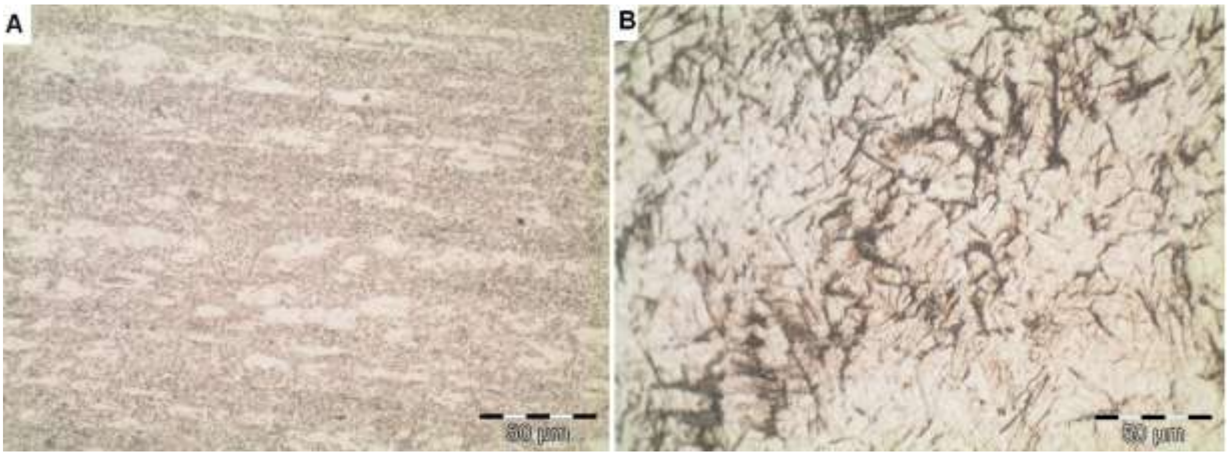

Figure 13 – Rolled samples (A) and forged with 20% of reduction to 1000° C.

It is observed in Figure 13.A the forming toward of the lamination process with grain size less than 50 µm and elongated. Figure 13.b shows a microstructure rearrangement from the forging process with grain size between 10 and 20 µm. Figure 14.A shows the rolled sample 3 with 30% reduction in height. Figure 14.B shows the sample 4 that was sintered and didn't suffer forming process.

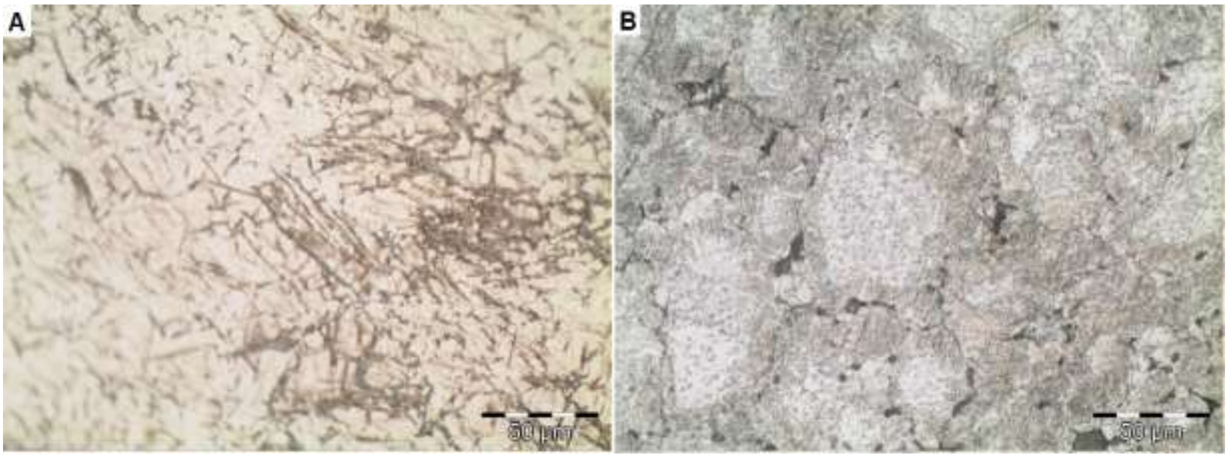

Figure 14 – Forged and rolled samples with 30% of reduction to 1000° C (A) and sintered (B).

Figure 14.A shows that there was little difference in microstructure compared to the sample with 20% reduction and grain size was between 10 and 20 µm. Figure 14.B shows the typical microstructure of a sintered sample with pores and grain size between 50 and 100 µm. Figure 15.A shows the sintered sample 5 with reduction of 20% in height performed to ambient temperature. Figure 15.B shows the sample 6 sintered with a reduction of 30% in height to ambient temperature.

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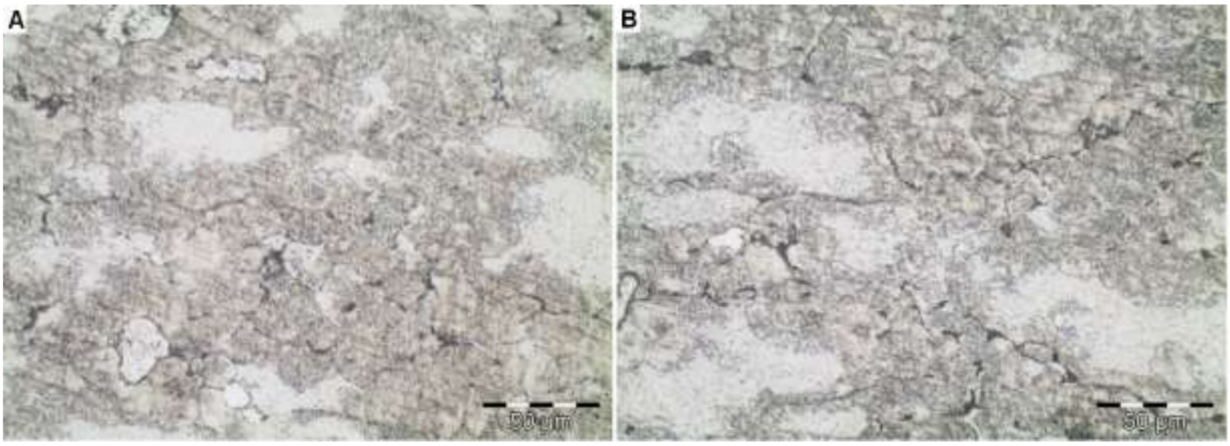

Figure 15 – Sintered and forged samples with 20% (A) and 30% (B) reduction in ambient temperature.

Note in Figure 15.A that there was a reduction of grain size that was between 20 and 80 µm. Figure 15.B demonstrates the same grain size that the sample with 20% reduction. However, there is no evidence showing that the forging performed the closing of the pores and the decrease of grain size, increasing the hardening and hardness. Figure 16.A shows the sample 7 sintered with reduction of 20% in height performed to 1000º C. Figure 16.B shows the sample 8 sintered with reduction of 30% in height to 1000° C.

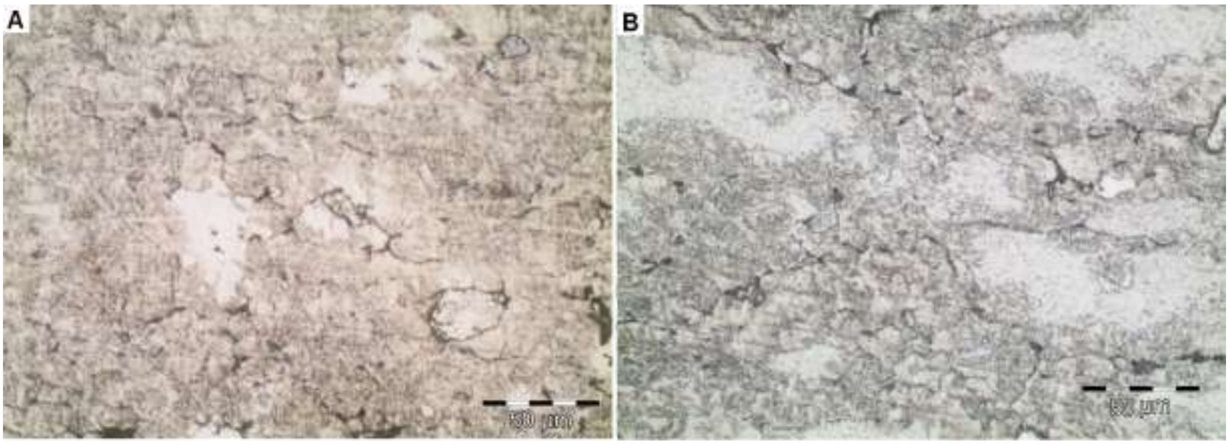

Figure 16 – Sintered and forged samples with 20% (A) and 30% (B) reduction to 1000° C.

It is observed in Figure 16.A and 16.B that there wasn't reduction of grain size relative to the same forming percentage to ambient temperature.

CONCLUSION

From the compressibility curve was defined the compaction pressure of 700MPa get an optimal densification. The hardness and micro hardness values of the sintered samples were less than 100HV. In the testing performed with the samples obtained by elemental powders compacting decreased considerable the stress used for compression, then to the cold test the reduction was 200N/mm^2. In

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the hot tests the reduction in the stress reached 410N/mm^2 compared to cold tests in the samples obtained from the elemental powders compression. During the forming the micro hardness of sintered samples increased for about 220HV. It was compared the hardness of the samples rolled and forged. The micro hardness values of the samples rolled and forged with reduction of 30% to 1000° C and of the sample got by powder metallurgy and forged were with 580 and 670HV, respectively. This high hardness of the forming last sample indicates that is due to the hardening, even reduced by the effect of temperature. The metallographic indicate that forging closed pores and modified the microstructure of the sintered material and reduced grain size of all samples.

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