Evaluation of Densification and Mechanical Properties of Hot Forged and Sintered AISI 4340 P/M Steel

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Abstract

The existing work has been undertaken to evaluate the densification and properties of sintered and hot forged AISI 4340 High Strength Low Alloy Steels by using elemental powders through powder metallurgical techniques. The following aspect ratios namely 0.25, 0.50, 0.75 and 0.90 were taken by using 1 MN Capacity hydraulic Universal Testing Machine. The green compacts have been sintered at 1100±10°C in hydrogen atmosphere and immediately forged at 1050±10°C by Friction Screw Press. Few forged steels were homogenized at 1050±10°C for 1hr, 2hrs and 3hrs in an electrical muffle furnace after sintering process. The sintered, forged and homogenized AISI 4340 steels were subjected in to densification studies and mechanical properties evaluation. And Lower aspect ratio performs such as 0.25 and 0.50 exhibited better densification properties than the higher aspect ratios such as 0.75 and 0.90. Sintered steels have exhibited lower strength and hardness due to poor density. But the forged and homogenized steels exhibit better mechanical properties then Sintered steels.

Keywords: Sintering, AISI 4340, HSLA steels, Mechanical Properties,

1. Introduction

Powder metallurgy plays a major role in the modern technology world. The Development of the Powder Metallurgy industries during the past years is largely attributable to the cost savings associated with net (or near-net) shape processing compared to other metal working methods, such as casting or forging. The conversion of caste or wrought component to powder metal provides a cost savings of 40% or more than that higher. PM typically uses more than 97% of the starting raw material in the finished part and is specially suited to high volume components production requirements. The advantages of using a powder metallurgy product are (a) Cost savings compared with substitute processes, and (b) Exclusive properties attainable only by the Powder Metallurgy.

Due to its economic nature in the auto motive sector, which consumes about 80% of structural Powder Metallurgy part production is the reason for choosing Powder Metallurgy on which majority of cases. Powder Metallurgy process enables the products to be made that are capable of absorbing up to 35% of selected fluids [1, 2]. In the earlier production of products from AISI 4340 steels has been done through conventional routes, for example metal casting forming forgings etc. The standard size blocks to the required shape and machining was done through the products from the metal cast rolled or drawn rods, billets. These were energy concentrated process which produce a large amount of scrap with material utility from 50%-80% [3]. Due to economic view, Fine machining, grinding and lapping operations made these products highly non- competitive. The current investigation adopts Powder Metallurgy route coupled with certain usual process to produce the components which has close tolerance with the design.

To design the exact outline of the component surface finish density strengths are required. Alloying powders required for AISI 4340 steel were taken and compacts were made and density up to 90% of full density was achieved. After compacting operation, sintering is carried out a temperature in the range of 0.5- 0.7TM. During this operation a numbers of pores were reduced, the pore shape has become smooth and grain growth takes place. In the current investigation is aimed to develop the AISI 4340 steel from elemental powder and subsequently sintered in hydrogen atmosphere. Some of the sintered steels have been subjected in to hot forging and homogenization operations. The sintered, forged and homogenized AISI 4340 P/M steels were subjected in to densification studies and mechanical properties evaluation [4].

2. Experimental Details

Atomized iron powder, chromium, manganese and nickel powders were supplied by Hoganes India Ltd., Pune, India. The chemical composition of the AISI 4340 powder is as shown in the table 1. The elemental powders were mixed in a pot mill for 12 hrs at room temperature. The basic characteristics of powder blend (AISI 4340) such as flow rate, apparent density, compressibility, and sieve analysis have been carried out using standard rate methods of testing.

Table 1: Chemical Composition of AISI4340 Steel

% C	% Mn	% Cr	%Si	% Ni	% Mo	% Fe
0.4%	0.75%	0.8%	0.3%	1.9%	0.25%	Balance

The blended powder mass was then compacted into cylindrical billets of aspect ratios (Height/Diameter) such as 0.25, 0.5, 0.75 and 0.90 were prepared by Universal Testing Machine of 100 tonnes capacity. The pressure level of 450±10 MPa was applied during compaction. Zinc Lubricant was used to avoid the various frictions between the die, punch and powder particles. After compaction indigenously developed ceramic coating was applied on the compacts and dried for one day. Sintering was carried out in a tubular furnace with protective atmosphere such as hydrogen at a temperature of $1100 \pm 10_0$ C for a period of 2 hours. The flow rate of the reducing gas is 250 ml/min. Hot upsetting of the sintered performs followed immediately after the sintering process. Dimensional measurements were accurately carried out after each step of hot deformation. Similarly density measurements were made after each deformation step by applying Archimedes's principle. The axial upsetting was continued up to the instance of formation of fine surface cracks. The forged AISI 4340 steel subjected in to mechanical properties evaluation. The fractographs of the tensile samples are also analyzed.

3. Results and Discussion

3.1. Densification Properties of AISI 4340 P/M Steels

Figure 1 shows the density bar graphs of the sintered and forged P/M 4340 steels. After sintering approximately 7.5% incremental in density is observed. Sintering atmosphere such as hydrogen atmosphere plays a major role during sintering process. More diffusion rate between the adjacent particles is exhibited due to the absence of chromium oxide layer along the surface of the powder particle during sintering. After sintering different aspect ratios of the steel, performs were subjected to hot forging at 1050 ± 10$_0$C with various pressure levels. Once forging is completed then the density was nearer to the theoretical density of performs. Figures 2 is drawn between the influence of initial perform geometry on the densification modes of sintered AISI 4340 steel performs during hot forging at 1050±10°C. A clear visual observation was made from the figure 2 and it indicates that lower aspect ratio.

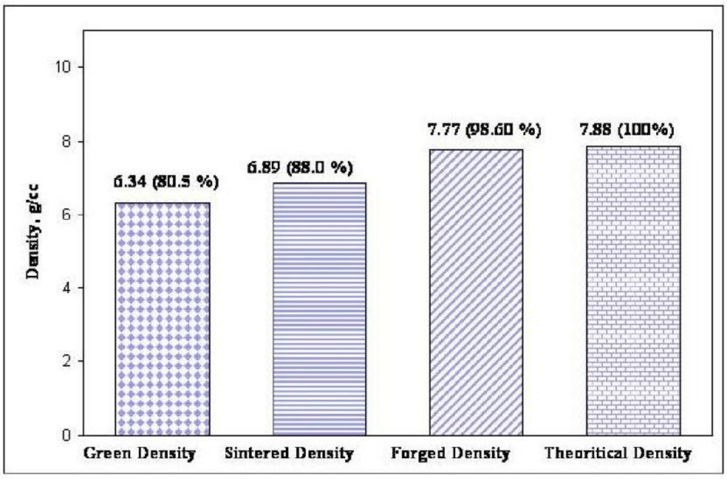

Figure 1: Densities of sintered and forged AISI 4340 P/M Steels

Ho/Do = 0.25 and 0.5 density comparatively more rapidly than 0.75 and 0.90 aspect ratio performs. The reason for lower aspect ratio performs density more rapidly compared to larger aspect ratio performs is quite low transfer due to reduced damping phenomena in smaller aspect ratios. The densification pattern in two larger aspect ratio performs namely 0.75 and 0.90 was found to be almost is the identical mode but only with the mild marginal improvement in densification in 0.75 aspect ratio.

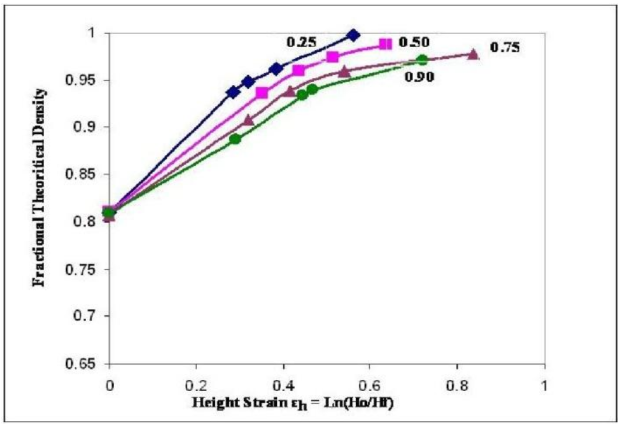

Figure 2: Height strain Vs Fractional Theoretical density for the AISI 4340 steel

Further the densification curves were found to follow a second order polynomial between the attained fractional density and the true corresponding height strains. The relation expressed is as follows,

$$(\rho f/ \rho th) = A_0 + A_1 \ln (Ho/Hf) + A_2 \ln (Ho/Hf)^2 \quad \text{----} \quad (1)$$

Where $(\rho f/ \rho th)$ = Fractional Theoretical Density,
ln (Ho/Hf) = True Height Strain and
A_1, A2 and A_3 are empirically determined constants.

The empirically determined constant A_0 virtually has close conformity with the initial perform density irrespective of the aspect ratio. Therefore during the hot forging the constant A_0 does not contribute to densification. However the constant A_1 is always found to be positive and is multiplied by the height strain implying there by that this constant in fact facilitates densification. But, always the negative values of constant A_2 with a low magnitude simply taper off the densification and thus, is determined [5]. Poisson's ratio is one of the most fundamental and practical dimensionless quantity which is extensively used in the forming of suitable P/M parts. The production of P/M parts through hot upsetting involves substantial flow of material before repressing action is employed. However, the repressing action must be introduced at the stages where surface cracking just begins. Therefore, it is apparent that the productions of P/M parts in the near vicinity of theoretical density, the design of perform geometry and forming dies are dependent upon Poisson's ratio [5]. This can be defined as the ratio between the diameter strain and height strain; it is proved [6, 7] that the Poisson's ratio for plastic deformation of fully dense material is 0.5.

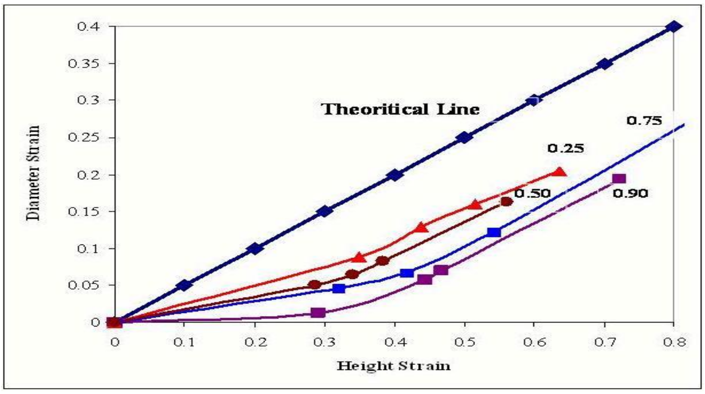

Figure 3: Diameter Strain Vs Height Strain for the sintered AISI 4340 steel

During hot upsetting of sintered powder metal, some material flows into pores and there is decrease in volume. For a given height reduction, the diameter of a powder metal cylinder will expand lesser than a fully dense material. Therefore, the Poisson's ratio for plastic deformation of sintered powder material will be less than one-half and will be a function of the pore volume fraction. Experimentally, Poisson's ratio can be determined by measuring the instantaneous deformed diameter calculated and height for each step of deformation, the resulting strain calculated for diameter and height was plotted in Fig. 3 and the ratio of these two parameters for the corresponding curve gives the value of Poisson's ratio. Further, it can be noted that the 45 degree line representing the relationship between diameter strain and height strain for a fully dense material and the curves for porous material are below the dashed line but gradually become parallel to it as full density is approached [9]. Figure 3 has been drawn between true diameter strain and true height strain to demonstrate the variation in the values of Poisson's ratio. The curves corresponding to lower aspect ratios such as 0.25 and 0.50 are much nearer to the theoretical line where as the data points 0.75 and 0.90 are slightly far away from theoretical 45 degree line.

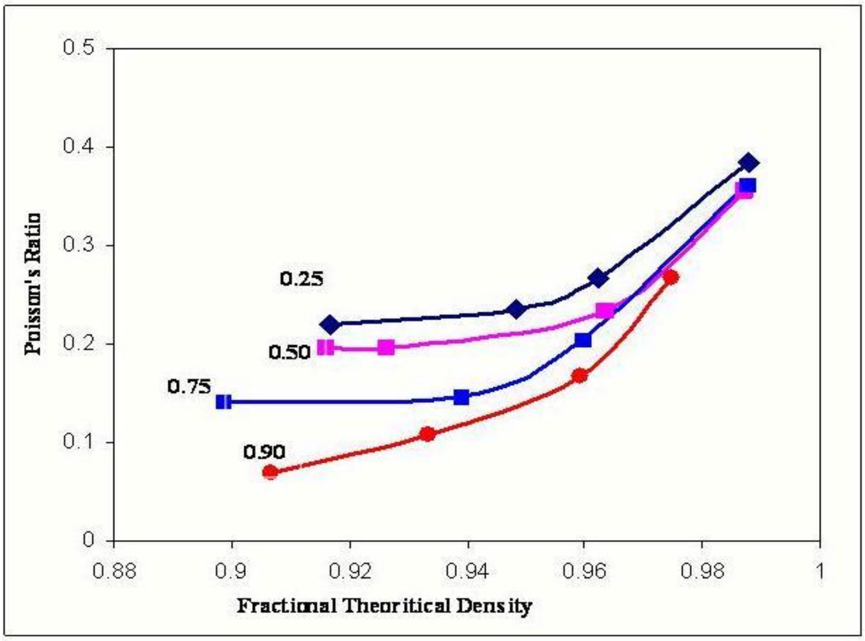

Figure 4: Poisson's Ratio Vs Fractional Theoretical density for the sintered AISI 4340

More over these curves for 0.75 and 0.90 are lying below the curves corresponding to data points of performs of 0.25 and 0.50 initial aspect ratio. It is observed that all data points remain below the theoretical line irrespective of aspect ratio ascertaining the fact that the values of Poisson ratio remain less than 0.5. However figure 4 was drawn to demonstrate the influence of initial aspect ratio and the relationship between Poisson ratio (υ) and the percentage of theoretical density % (ρf/ρth). Observing the curve shown in figure 6 it is observed that the influence of initial aspect ratio is marginal [8]. However, characteristically the curves shown are similar. When attained density is almost 100 percent, these curves indicate the tendency to approach to a limiting value of Poisson's ratio equal to 0.5 [9].

4. Mechanical Properties of Sintered and Hot Forged AISI 4340 Powder Performs

The mechanical properties of sintered and forged AISI 4340 steels are tabulated in the table2. From the table 2 forged AISI 4340 steel is having the tensile strength of 724 MPa with an elongation of 7 percent. But lowest tensile strength (683 MPa) and hardness (30 HRC) are observed for the sintered steels. Lowest tensile strength and hardness for the sintered steel is due to the lower sintered density. The homogenized steels are having higher tensile strengths of 746 MPa, 764 MPa and 762 MPa for homogenization of one hour, two hours and three hours respectively.

Table 2: Mechanical Properties of sintered and forged AISI 4340 steel performs

Condition	Yield strength MPa	Young's Modulus GPa	Tensile Strength MPa	Percent Elongation (%)	Hardness HRC
As sintered	341	174	683	4.45	30
As forged	496	176	724	6.9	30
1 hr Homogenization	514	186	746	9.6	34
2 hr Homogenization	538	186	764	11.6	36
3 hr Homogenization	534	180	762	10.8	36

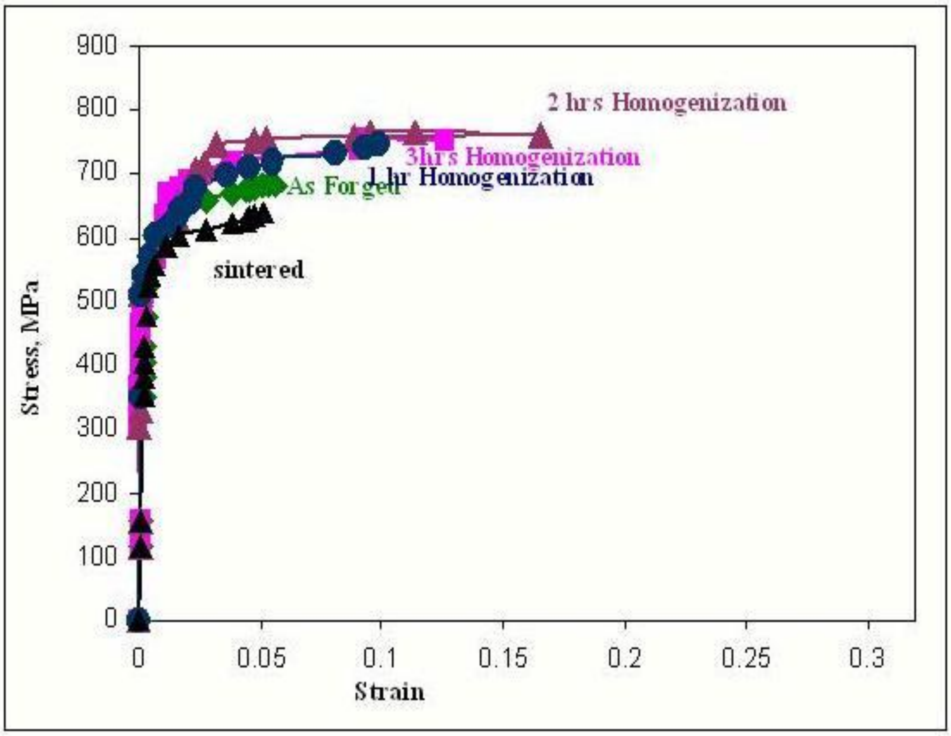

Figure 5: Stress – strain curves for sintered and forged P/M steels

Similarly after homogenization the hardness and elongation values are also increased. Especially the steels homogenized for two hours show better tensile strength and hardness [10]. But the three hour homogenized 4340 steels do not show much difference in tensile strength and hardness. The stress – strain curves for forged and homogenized P/M steels are shown in the figure.5.

5. Conclusions

Based on the review taken and analysis made on the experimental data and the calculated parameter, Sintered AISI 4340 HSLA steel exhibited lower density than the forged and homogenized steels. The Poisson's ratio with respect to density attained has been found to be mildly dependent upon the initial perform aspect ratio. Further, the basic nature has been found to be same when the relationship is established between the Poisson's ratio (υ) and the % theoretical density attained. These curves have tended to approach to a limiting value of 0.5 in the near vicinity of 100% densification. The Characteristic nature of densification curves between % attained theoretical density and the true height strain curves are found to correspond to a second order polynomial of the form (ρf/ρth) = a0 + a1 ln(H0/Hf) + a2 [ln(H0/Hf)]2 where a0, a1 and a2 are empirically determined constants dependent on the initial aspect ratio. And also The Data points for the relationship between the true diameter and the true height strains lay upsetting conditions (100% percent densification is not possible). Finally The Forged and two hours homogenized steels exhibited better mechanical properties than the other steels. Sintered steels show inferior mechanical properties due to their lower density.

References

[1] German, R.M., 1998. *Powder Metallurgy of Iron and Steel*. John Wiley & Sons, Inc., New York, pp. 276–279.

[2] Kuhn, H.A., Downey, C.L., 1971. Deformation characteristics and plasticity theory of sintered materials. *International Journal of Powder Metallurgy* 2 (1), 15–25.

[3] K.S. Pandey,"Die designs for Hot Forging of Sintered Iron Powder Performs", *Quarterly International Journal of Powder Metallurgical Science and Technology,* Vol.4, No.1, pp.35 -46, (1992)

[4] R. Chandramouli, T.K. Kandavel, D. Shanmugasundaram, T. Ashok Kumar, "Deformation, densification, and corrosion studies of sintered powder metallurgy plain carbon steel performs", *Materials and Design*, 28 (2007), pp. 2260–2264.

[5] Pandey KS. Some investigations on the cold deformation behavior of sintered Aluminum – 4% copper alloy powder performs. *Quarterly International Journal of Powder Metallurgy Science Technology,* 1991; 2(4): pp45–54.

[6] Sowerby, R., O'Reilly, I., Chandrasekaran, N., Dung, N.L., 1984. Materials testing for cold forging. *Journal Engineering Materials Technology*, 106, 101–106.

[7] W B James, M J McDermott and R A Powell, "Powder Forging", *Metals Handbook*, Vol. 14, Tenth Edition, 1988. Pp.123-124.

[8] Pandey KS. Salient characteristics of high temperature forging of ferrous perform Key Engineering Materials, vols. 29–31. *Switzerland: Trans Tech Publications*; 1989. pp. 465–86.

[9] A. Rajesh Kannana, K.S. Pandey, S. Shanmugam, "Some investigation on the cold deformation behaviour of sintered iron–0.8% carbon alloy powder performs". "*Journal of Materials Processing Technology,* vol 2 0 3 (2 0 0 8), pp. 542–547.

[10] H Sanderow and R Spriko, "The Mechanical Properties of Powder Forged Steels - Effect of Composition and Heat Treatment", *Advances in P/M & Particulate Materials,* 1996, Vol. 4, p. 13-311-13-327.