Densification Mechanism and Mechanical Properties of Sintered Iron and Iron-Oxide (FeO) Composites During Hot Forging

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ABSTRACT

Present investigation pertains to evaluate the densification mechanism and mechanical properties of sintered Fe, Fe-2.5%FeO and Fe-5.5%FeO during hot upsetting to disc and square cross-section bars. Compacts of initial aspect ratios of 1.18 and 1.31 were prepared from iron powder and blended Fe-2.5% FeO and Fe-5.5%Feo using suitable die, punch and bottom insert on 1.0 MN capacity U.T.M in the pressure range of 490 ± 10 MPa and 520 ±10 MPa respectively. These Compacts of each composition in the density range of 82±1 per cent of theoretical were sintered at 1150 ±10^0 C for a period of 120 minutes under the protective ceramic coating. Sintered compacts of 1.18 were axially hot upset forged to different height strains whereas the performs of 1.31 aspect ratio were forged to square cross-section (~13mm X ~13 mm) bars of approximate length of 100±5mm. Analysis of experimental data and calculated parameters revealed the existence of third order polynomial densification for both w.r.t height strain and poisson's ratio. Addition of FeO in iron has raised the strength but show a substantial drop in ductility.

Key words: *Hot forging, Densification, Diameter strain, Height strain, Poisson's ratio*

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INTRODUCTION

P/M products are found in virtually all facts of life, without them, many achievements and conveniences of our civilization would be inconceivable. The success of the P/M industry for the past four decades derives from its ability. Manufacture of metal components via P/M techniques embraces the high rate of conventional processes with low losses due to minimal machining requirements and excellent material utilization [1]. However, the attained density in P/M product is the predominant factor while considering their performance aspects. Mass-produce complex structural parts with savings in labour, material and energy in recent year's raw dimensions has been with the achievement of full density and improved control of purity and microstructure. This has resulted in the fabrication of high performance materials, permitting extended service life. The commercialization of powder based high-performance material emerged as a major breakthrough in metal working technology. The resultant densification in these proportions of the component is negligibly small and hence with certainty it cannot claimed that percent dense products can be produced through P/M route unless otherwise combinations of two, or more than two, deforming processes are adopted,i.e., one following the other. The essential features of powder metallurgy are not only production of powder and consolidation into a solid form by the application of pressure band heat at a temperature below the melting point of the major constituent [2].

Almost all materials that are utilized today is a composite since it is almost impossible to find a material employed in its purest form. Material in its purest form virtually does not meet the engineering requirements with a particular design constraint. Therefore, Two or more materials in combination are expected to possess the required properties and do provide an appropriate solution to the intricate material selection is a problem for a given engineering application. However, the principle of composite is not new. Basically, composites as a class of engineering materials provide almost unlimited potential of enhanced strengths, stiffness and high temperature functionality without detoriation over limited materials. One of the methods of producing composites materials in a given shape is hot powder perform forging yielding high density with improved mechanical properties. Further, it is important to note that the way the high density in P/M performs are achieved plays an important role in achieving the desired mechanical properties. In working of sintered powder performs, the mass constancy principle is invoked as the volume keeps changing upon deformation. Densification in P/M performs depend upon the mode of loading, perform geometry and its initial density, the pore shape, size and its distribution inside the perform .In the present investigation effect of composition mechanism of sintered iron, Fe-2.5% FeO and Fe-5.5% FeO composition performs during hot forging is investigated.

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EXPERIMENTAL DETAILS

The materials required to carry out the present investigation are iron powder and iron oxide. Atomized iron powder of -180μm was obtained from M/s Sundram Fasteners Hyderabad, A.P, India. The chemical purity was found to be 99.56 percent with 0.44% insoluble impurities. The basic characteristic features of iron powder, Fe-2.5% FeO and

Fe-5.5% FeO blends were carried out. The above mentioned powder mixture were taken in a separate stainless steel pots. These pots were tightened rigidly on the pot mill and allowed to operate for 30 hours to get homogeneous powder blend. Molybdenum di sulphide is needed as a lubricant during compacting. Suitable die, punch and butt are required for compacting the metal powders. The charterzation of iron and iron oxide powders were also done.

Sieve size analysis of iron powder is given in Table-1.

Table-1 Characterization of Iron powder

	Sieve size,µm									
Wt% of powder ret.	+150	+125	+106	+90	+75	+63	+53	+45	+37	-37
Wt% of powder ret. On each sieve	10.100	21.896	9.328	2.213	19.876	13.013	11.103	6.089	0.157	6.208
Cum. Wt% powder ret.	10.100	31.996	41.324	43.537	63.413	76.426	87.529	93.618	93.775	99.983

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POWDER BLENDING, COMPACTION AND CERAMIC COATING

The preparation of iron powder and iron oxide was made taking known amount of its compositions. Homogeneous powder blends of Fe-2.5% FeO and Fe-5.5% FeO were prepared on a pot mill for a period of 30 hours and the blended powder is used for compacting. The powder blends of the respective powder weights taken were prepared on a 1.0MN capacity universal testing machine using suitable die, punch and bottom insert. compacts in the density range of 82±1 per cent of theoretical with 1.18 and 1.31 aspect ratios were prepared by taking pre-weighed powders and by applying pressures in the range of 490± 10 MPa. 15 compacts of each aspect ratio and each composition were prepared including iron powder. All compacts were coated with the indigenously developed ceramic coating and dried. This is to protect the compacts during sintering.

SINTERING AND HOT FORGING

Sintering was carried out in an electric muffle furnace for a period of 120miniutes at $1150^{0}\pm10^{0}$C and the preforms of 1.18aspect ratio hot upset forged to different height strains and the performs of 1.31 initial aspect ratio were forged to square (~13mmX~13mm) cross-section bars of length 100±5mm.the sintered samples of aspect ratio of

1.31 were upset forged on both sides of cylindrical specimen to obtain square cross-section bars. These bars were machined for tensile testing. The height strain (hf), contact diameter (dc) was measured for all upset forged samples. Measurements have been carried out to calculate deformation, height strain and diameter strain. The density also measured using Archimedean principle. The tensile specimens prepared from the square cross-section bars were tested under on uniaxial load on Hounsfield tensometer. Initial gauge length and diameter has been measure before testing. Final gauge length and diameter has been measured after testing by combining the two fractured parts. Fracture load and maximum load has been noted down from which the tensile strength, yield strength, percentage elongation and percent area reduction were calculated.

RESULTS AND DISCUSSION

The densification mechanisms have been investigated with the relationship between fractional theoretical density, diameter strain vs height strain and fractional theoretical density vs poisons ratio for all three compositions.

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Fig 1 has been drawn between fractional theoretical density and height strain for all the three above said compositions. The characteristic nature of all these curves is found to be quite similar to each other and further found to depend upon the powder height, mass and the compositions. The technical analysis of theses plots indicated that they conformed to third order polynomial equations of the given form: $(\rho_f/\rho_{th})= a_1\varepsilon_h^3+a_2\varepsilon_h^2+a_3\varepsilon_h+a_4, \varepsilon_h=\ln(H_0/H_f)$; where '$a_1$', '$a_2$', '$a_3$', '$a_4$' are empirically determined constants. The values of regression coefficient 'R^2' in each case was found to be close to unity and, hence, the best fit curves. These constants values are tabulated in table-1.

Fig 2 shows the relationship between diameter strain vs height strain. It is observed that almost all data points match fairly close with the straightline equation.the lower aspect ratio preforms densified at a much faster pace compared to higher aspect ratio preforms. Numerical analysis of these curves indicates that theses data points corresponded to a second order polynomial of the form: $\ln (D_c/D_0) = a_1\varepsilon_h^2+a_2\varepsilon_h+a_3 = (\rho_f/\rho_{th})$ where 'a_1', 'a_2' and 'a_3' are constants. The 'R^2' value found to be 0.99, which confirms a good curve fitting which matches to reliable empirical equation. The constant values are tabled in Table-2.

Fig 3 drawn between the fractional theoretical density and poisons ratio. It is observed that all data points remained below the theoretical line irrespective of aspect ratio ascertaining the fact that the value of poisons ratio will always remain less than 0.50. The data points correspond to lower aspect ratio remain closer to theoretical line and the higher aspect ratio performs away from the theoretical line. The regression analysis of this curves has revealed that they followed a second order polynomial of the form: $\nu_p=a_1(\rho_f/\rho_{th})^2+a_2(\rho_f/\rho_{th})+a_3$ where 'a_1', 'a_2'and 'a_3' are empirical constants. The regression coefficients in all cases beyond 0.99 indicating the fact that the proposed relationship has been an accurate one. The empirical constants values are tabulated in table.3.

Mechanical properties of the systems investigated and are listed in Table-4.

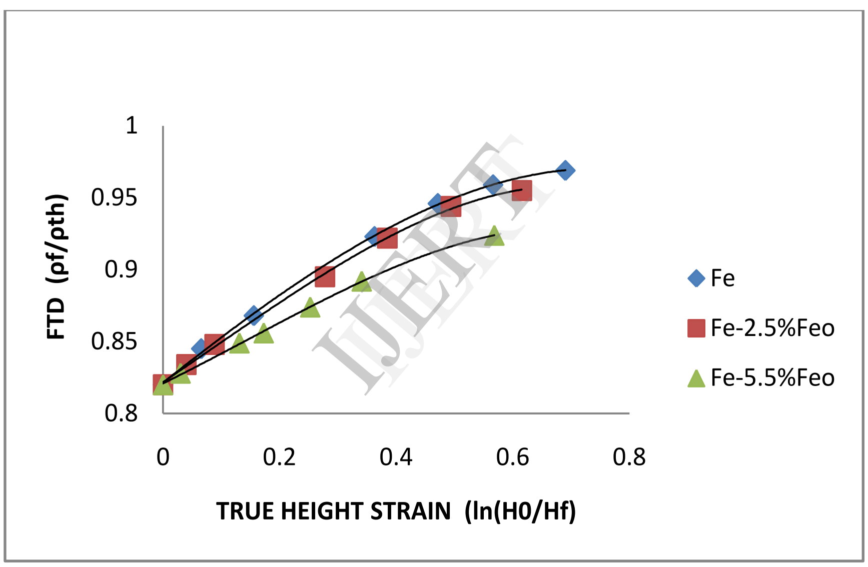

Figure.1: Relationship between Fractional Theoretical Density and True Height Strain

In Figure 1 the characteristic nature of these curves are similar for all three compositions. It has been Observed that iron composition (Fe) exhibited improved density then followed by iron with 2.5% Feo Iron with 5.5% Feo shows lesser density. The density is improved for all the three cases.

Table.1: Coefficients of third order polynomial form: $(\rho_f/\rho_{th}) = a_1\varepsilon_h^3+a_2\varepsilon_h^2+a_3\varepsilon_h+a_4, \varepsilon_h=\ln(H_0/H_f)$

composition	a_1	a_2	a_3	a_4	R^2
Fe	-0.138	-0.06	0.322	0.821	0.999
Fe-2.5%Feo	-0.255	0.067	0.273	0.821	0.999
Fe-5.5%Feo	0.249	0.111	0.198	0.82	0.999

In table 1 shows coefficients of the third order polynomial equation with empirical constant Values. The regression coefficient R^2 shows 0.999. The curve fitting is normal.

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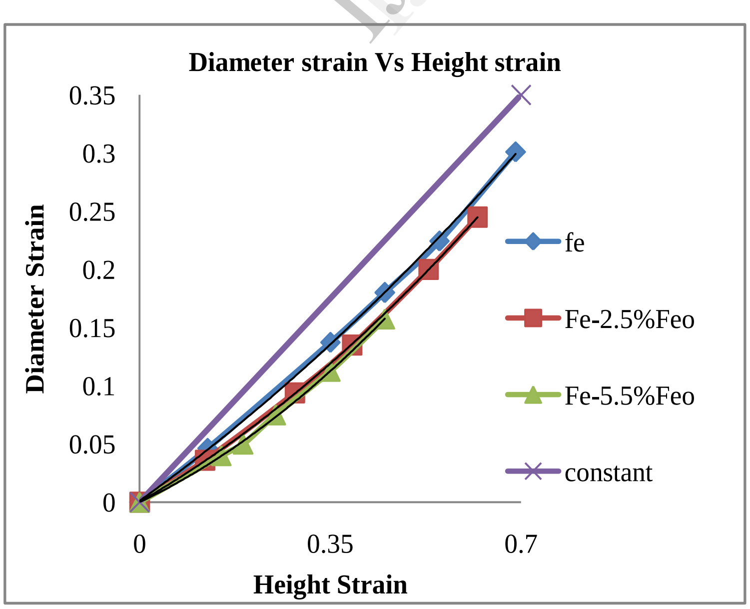

Figure.2: Relationship between diameter strain and Height strain

In Fig 2 It is observed that almost all data points match fairly close with the straight-line equation. The

Iron (Fe) preforms densified at a much faster pace compared to Fe-2.5% and Fe-5.5% performs. Numerical

Analysis of these curves indicates that theses data points corresponded to a second order polynomial equation form.

Table.2: Coefficents of second order polynomial
Form: $\ln (D_c/D_0) = a_1\varepsilon_h^2+a_2\varepsilon_h+a_3 = (\rho_f/\rho_{th})$

composition	a_1	a_2	a_3	R^2
Fe	2.713	-3.827	1.613	0.999
Fe-2.5%Feo	0.809	-0.427	0.116	0.999
Fe-5.5%Feo	-0.718	2.211	-0.993	0.999

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In table 2 it shows the 'R^2' value found to be 0.99, which confirms a good curve fitting which matches to reliable empirical equation.

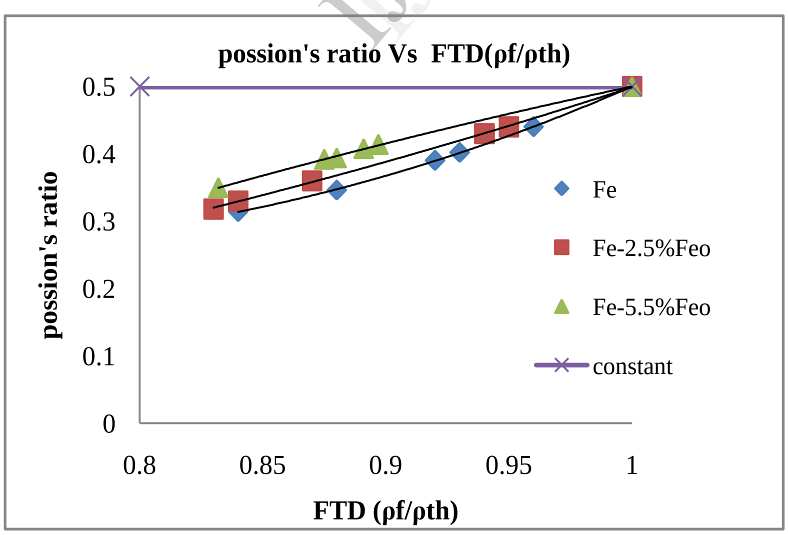

Figure.3: Relationship between Poissons ratio and Fractional Theoretical Density

Table.3: Coefficents of second order polynomial form: $\nu_p=a_1(\rho_f/\rho_{th})^2+a_2(\rho_f/\rho_{th})+a_3$

composition	a_1	a_2	a_3	R^2
Fe	0.141	0.33	0.001	0.999
Fe-2.5%Feo	0.202	0.269	0	0.999
Fe-5.5%Feo	0.287	0.221	0	0.999

Table 4: Mechanical Properties of Upset Forged Square Cross-Section Bars of Iron, Fe-2.5% FeO and Fe-5.5% FeO Composites-As Forged Condition

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Composition	Yield strength(MPa)	Tensile Strength (MPa)	% EIongation	% Area reduction
Iron	-	473	24.3	49.4
Fe-2.5% FeO	557	658	15.38	37.44
Fe-5.5% FeO	698	698	10.13	14.97

Above table indicates that the addition of FeO in iron has increased the yield and, the tensile strengths but has substantially reduced the percentage elongation and area reduction. This establishes that though there is an increase in strength values, but, there is a definite drop in % elongation and % area reduction, i.e., in ductility.

CONCLUSIONS

Based on the critical analysis of the experiment data and the calculated parameters, following conclusions are drawn:

1. Densification followed third order polynomial w.r.t true height strain whereas diameter strains with true height strain and Poisson's ratio w.r.t relative density. Poisson's ratio tended to approach to unity but could not achieve meaning thereby that cent per cent densification was not attained.
2. The densification pattern with respect to true height strain for all the systems considered.i.e.,Fe,Fe-2.5%Feo,Fe-5.5% FeO were found to follow a polynomial equation of third order.
3. All the data points corresponding to the plots of true diameter and true strains have been found below the theoretical line of slope0.5 indicating that the value of poisons ratio tends to approach a value 0.5 but never reaches it. This is true irrespective of preform geometry.
4. Two modes of densification are found to exist. the first mode of densification corresponded to a negligible rise in poisons ratio accompanied by a rapid rise in density followed by the second mode of densification where a rapid rise of poisons ratio value corresponded to an attainment of higher levels of fractional theoretical densities.
5. Mechanical properties such as yield strength, tensile strength are found to be beneficial and Enhanced on addition of Feo but ductility dropped.
6. Present investigation leads the way to produce P/M composites with high densities and enhanced properties.

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