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An Experimental Investigation on Deformation Behaviour of Fe-C-Mn Powder Metallurgy Sintered Composites

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Abstract:

An experimental investigation was conducted to find formability and their relation on sintered powder metallurgy three element (Fe-C-Mn) powder metallurgy preforms. Some of the powder particle in the preforms was in sub-micron level. Cold up-set forming tests were conducted in tri-axial state condition on the aforesaid composite preforms of iron with 0.70% manganese and three different percentage of carbon content as 0.05%, 0.10% and 0.15%. The powders are homogeneously mixed on weight basis and then gradually compacted up to 1.2 G Pa pressure. The 20 mm diameter and 0.45 aspect ratio preforms were sintered at 1050 ± 50C. Sintered preforms were cold deformed with uniform incremental loading until the initial creak appeared on their lateral surface. The effects of different percentages of carbon on the iron based composite preforms were investigated thoroughly in the cold deformation experiment. The workability and strain hardening behaviour of the composites was also analysed and presented. From the experimental data, the higher initial density preform Fe-0.10%C-0.70%Mn exhibited greater values in formability parameters.

Keywords: Cold up-setting, Work hardening, Deformation, Compacting, Sintering

I. INTRODUCTION

The process of powder metallurgy [P/M] is collecting powder, blending with correct proportion, compaction to standard pressure and then sintering. There is tremendous development on powder metallurgy products in industries from the past four decades. This technology achieved cost and material saving, better dimensional and weight control and good strength compared to conventional castings and forgings [1]. This micro pore always renders the P/M material weak and reason for origination of creaks during service [2]. Selvakumar et al. presented a detailed research report on the deformation behaviour of cold upset forming of sintered Fe-C-Mn composite performs [3].

Adding carbon and manganese with iron increases hardening and prevents dis-location in the iron atom crystal lattice from sliding past one another and also increases rust resistance strength and weldability [4]. Particularly, manganese improves forging and rolling properties, good strength, toughness, stiffness, wear resistance and hardenability [5,6]. In commercial practice, a three element Fe-C-Mn powder composite material is used in application like heat resisting bearings, self-lubricating bearings, brake drums, pores metallic sleeves thrust bearings, flanges and other corrosion resistance metallic parts because of their porosity, strength and thermal conductivity in nature. Operating temperature of these parts is approximately 6000C according to Nadezda et al. [7].

Formability or workability is the optimum ability of metal undergoes plastic deformation in a specific metal working process before initial crack [8]. Abdel-Rahman and El-Sheikh [9] proposed the criterion called formability stress index ($\beta\sigma$) for describing the effect of the mean stress, the effective stress and relative density with the help of the two theories, proposed by Kuhn-Downey and Whang-Kobayashi. When pores P/M materials undergoing cold deformation, experiencing matrix work hardening at the initial stage and geometrical work hardening at the metal flow in to the pores [3]. The total work-hardening in P/M preforms is due to densification as well as cold working of the base material surrounding the pores [10]. The strain hardening is a phenomenon of slip caused by the previous plastic deformation which in turn is caused by dislocations interacting with each other [11]. Mohan Raj et al. investigated and determined the instantaneous strain-hardening exponent (ni) and the instantaneous strength coefficient (ki) of iron based three element sintered P/M preforms at tri-axial state cold upsetting [12].

A very few literature were found which deals with the three element iron based sintered powder composites. In this composite, the carbon and manganese particles are reported in sub-micron size and experiments were conducted under tri-axial stress state condition at room temperature. The present investigation was an attempt to evaluate the effect of the formability parameter and to find out the best quantity of carbon among 0.05%, 0.10% and 0.15% to achieve the better formability properties in the proposed Fe-C-0.70Mn sintered composites.

II. THEORETICAL FORMULATION

A. *Formability stress parameters (β_σ)*

A uni-axial stress state compression never prevail the ideal data of actual cold upsetting operation. To get the actual outcomes of deformation test flow properties of a preform, the stresses in all three directions should be considered. To know the formability results of the specified composite preforms, following parameters were referred from Mohan Raj et al. [12].

Formability or workability index ($\boldsymbol{\beta_\sigma}) = \left(\frac{3\sigma_m}{\sigma_{eff}}\right)$ (2. 1)

The instantaneous strain hardening index $(\boldsymbol{n_i}) = \frac{In\ (\sigma_m/\sigma_{m-1})}{In\ (\varepsilon_m/\varepsilon_{m-1})}$ (2. 2)

The Instantaneous Strength Coefficient $(\boldsymbol{k_i}) = \frac{(\sigma_m - \sigma_{m-1})}{(\varepsilon_m^n - \varepsilon_{m-1}^n)}$ (2. 3)

The mean stress $(\boldsymbol{\sigma_m}) = \frac{(\sigma_z+\sigma_r+\sigma_\theta)}{3}$ (2.4)

III. EXPERIMENTAL DETAILS

The purpose of the experimental investigation to find out deformation behaviour of Fe-C-0.70Mn sintered P/M composite preforms with different carbon content as 0.05 %, 0.10 % and 0.15 % for the tri-axial state condition. To analyse and compare the deformation behaviour of the various carbon content Fe-C-0.70Mn P/M preforms, it is essential to establish the relationship between the various parameters of formability like instantaneous strain hardening index (n_i), instantaneous strength coefficient (k_i) and the formability stress index (β_σ) under the tri-axial stress state condition. The relative density of each preforms also played a vital role in the performance since the presence of pores.

A. Materials preparation

The matrix element of the three elements composite was the iron powder, which was analyzed and found to be of 99.79% purity. Carbon and manganese powder were obtained as laboratory grade with 99.9% purity. The iron and carbon powders were mixed on weight basis with 0.70 % Mn. The carbon contents were 0.05 %, 0.10 % and 0.15 % and remaining was iron. The composite powder was then milled for 12 hours in a high energy ball mill (Fritsch- Pulverisette - 6) with toluene as a wetting agent. The carbon particle was found in sub-micron size after ball milling noted by the particle measuring machine Malvern-v2.0 (Figure 1). The SEM image (Figure 2) shows the acicular pattern of the powders with sub-micron sized powder elements distributed throughout the material. Table 1 indicates the theoretical density of elements in the composite.

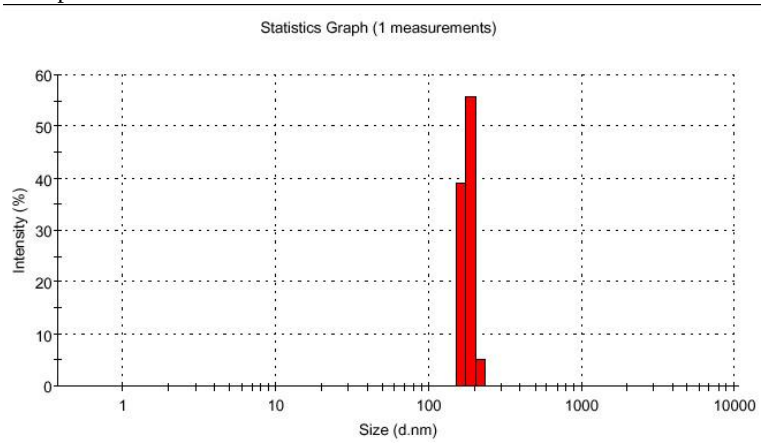
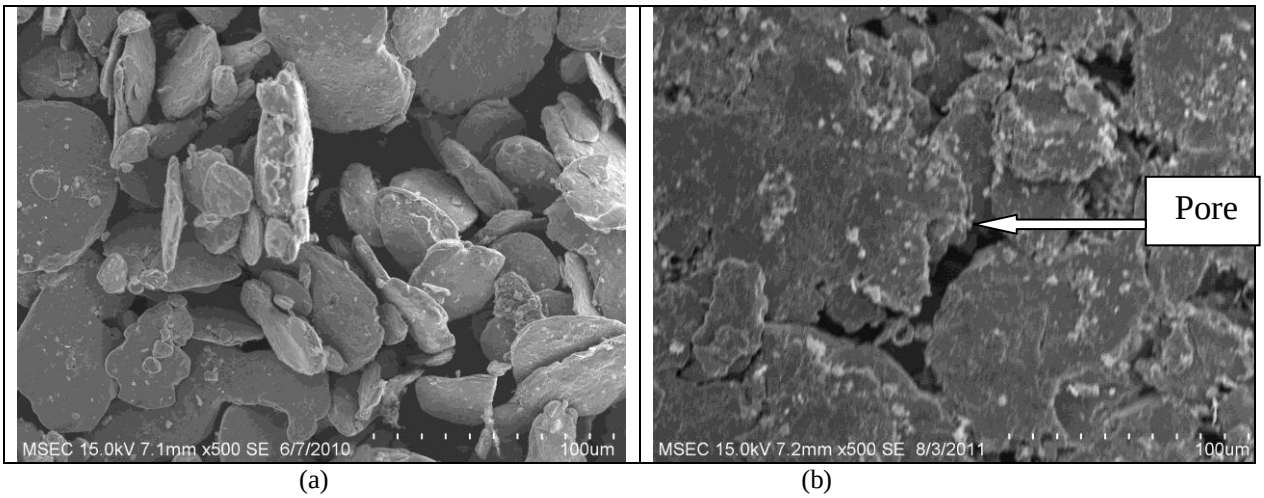


Fig.1. Size of carbon particle after ball milling by particle size measuring machine Malvern-v 2.0



(a) (b)

Figure 2. (a) SEM image of Fe-0.10%C-0.70%Mn composite. (b) SEM image of Fe-0.15C-0.70Mn compact after compacted with 1200 MPa. pressure.

Table 1. Theoretical Density of Elements in the Composite

Sl. No.	Elemental powder	Density in g / cc
1	Iron (Fe)	7.850
2	Carbon (C)	2.267
3	Manganese (Mn)	7.874

B. Compaction

The powder was then compacted by gradually applied Pressure up to 1.2 GPa. in UTM. The die set was made by high carbon high chromium steel, applied thoroughly with Molybdenum di sulphide (MoS2) as a lubricant, on all the butting area to avoid the sticking of the powder to these surfaces. The powder was compacted to 20 mm diameter preforms with 0.45 aspect ratio. American Society for Testing and Materials (ASTM:E9) and Metal Powder Industries Federation 254 (MPIF) standard 42 was followed for compaction [13]. The Figure 2 clearly shows the open pores in between the powder particles, with different size and shape in the compacts.

C. Sintering of compacts

Before sintering, the compacts were applied with two layer of indigenously developed ceramic coating 900 each other and then allowed to dry. Electric muffle furnace was used to heat the compacts to 1050^0 C for one hour and then allowed to cool in the furnace itself to 24 hours. It was noted that the preforms content had become spheroid structure except Fe-0.15%C-0.70Mn after sintering and previously all were acicular. Figure 3 presences the detail of preforms after sintering.

D. Deformation analysis

The deformation tests were conducted in a compression testing machine. Before that the initial dimensions of the each specimen like initial diameter, initial height and the initial preform fractional density were recorded. The incremental loading was applied to the preforms in step of 50 kN. Deformation process was carried out until the appearance of first visible crack on the lateral surface. After each interval of loading, dimensional changes in the specimen such as height after deformation, top contact diameter, bottom contact diameter, bulged diameter and density of the preform were measured. Figure 4 represents the schematic diagram of upset forming before and after deformation. The change of grain boundary of the specimen after sintering and after deformation test is represented by figure 5.

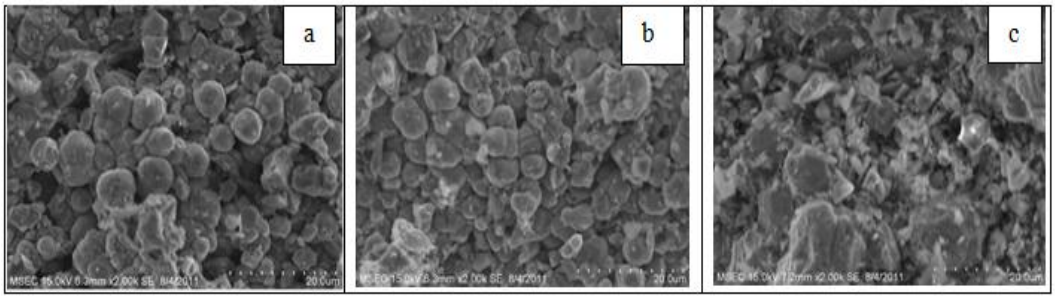


Fig. 3. SEM image of (a) Fe-0.05 %C-0.70 %Mn and (b) Fe-0.10 % C-0.70 Mn and (c) Fe-0.15 % C-0.70 Mn compacts after sintering in 1050^o C.

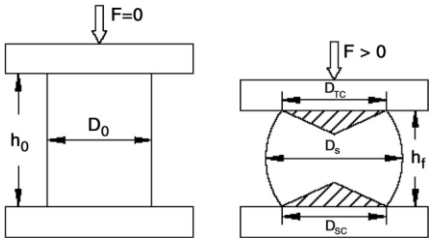


Fig. 4. Cold upset forming before and after deformation (Narayanasamy et al 2008)

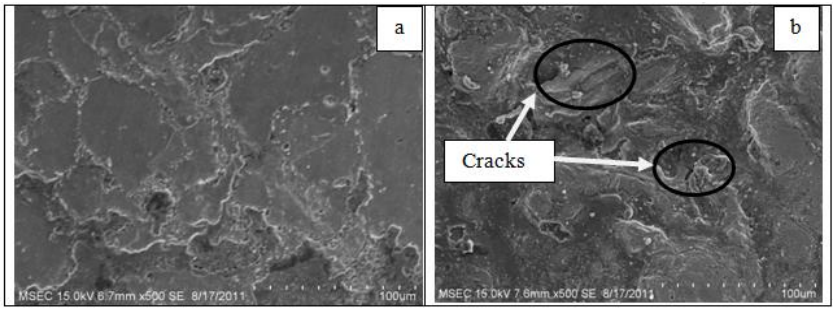


Fig. 5. Grain boundary of the specimen Fe-0.15 %C-0.7Mn after (a) sintering (b) deformation.

IV. RESULTS AND DISCUSSION

A. Microstructure investigation

As already specified, the preforms Fe-0.05%C-0.7%Mn, Fe-0.10%C-0.7%Mn and Fe-0.15%C-0.7%Mn were undergone microstructure investigation. The SEM images of the above said preforms (figure - 3) were put in Auto Cad 2010 to measure the pore parameters. The data were described in table no. 2. From the table 2, it has been absorbed that, the preform having 0.10 % of carbon content have less average bore size correspondent to higher value of relative density. The preform Fe-0.05%C-0.70%Mn contained higher average pore size and lower relative density. As described earlier, the carbon particles as small as sub-micron size, entered to the pores of the specimens and filled it. In 0.05% C specimen, the carbon quantity was less and in the 0.10% C content was more. In the case of the preform Fe-0.15%C-0.70Mn, the micro structure has not been changed and maintained as acicular before and after sintering. Figure 5 represents the grain boundary system of preforms after sintering and after deformation.

TABLE 2. PORE PARAMETERS OF COMPOSITES AFTER SINTERING

Composites	Av. area	Av. perimeter	Av. diameter	R. g/cc
Fe-0.05%C-0.70%Mn	9.06 μm^2	10.67 µm	3.39 µm	0.906
Fe-0.10%C-0.70%Mn	7.88 μm^2	9.61 µm	3.06 µm	0.920
Fe-0.15%C-0.70%Mn	9.01 μm^2	10.64 µm	3.37 µm	0.902

Note: "Av" means average and "*R*" represents relative density.

B. XRD Analysis

XRD is a non-destructive analysis method which evaluates crystallographic structure, chemical composition, and physical properties of materials. Rigaku-Ultima-3 difractometer with Cu-Kα radiation (λ=0.154056 nm) was used to getting XRD patterns to the specimens. Data were collected over the 2θ range 20-80^0 with a step size of 0.02^o and step time of 4 sec. Fe_3C compound formed by the combination of matrix iron and carbon at the elevated temperature 950^0 C, generally provides significant amount of strength to the preforms and obtains in the preform containing 0.10C and 0.70Mn. Other compounds like manganese carbide (MnC_8 and Mn_5C_2), are unable to provide high impact in the strength of preform since their quantity is very low (< 1.00%).

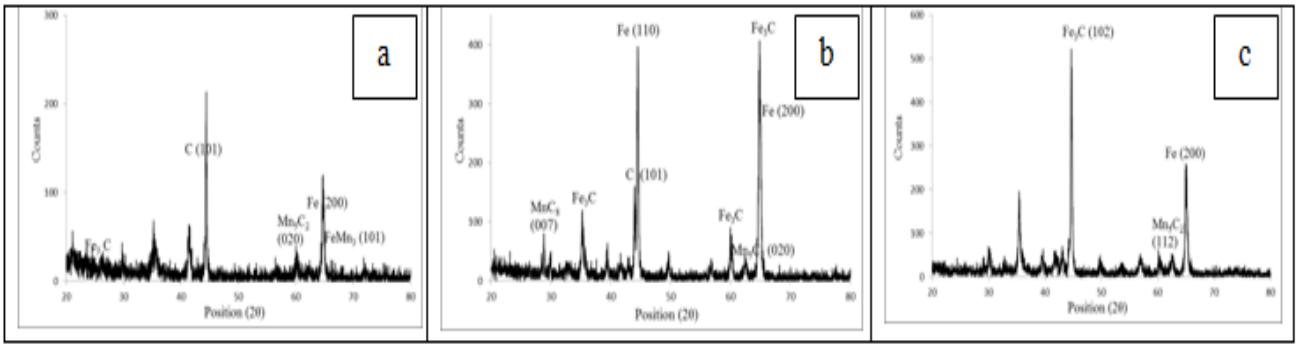


Fig. 6 XRD pattern of preforms (a) Fe-0.05C-0.70Mn (b) Fe-0.10C-0.70Mn and (c) Fe-0.15C-Mn.

Figure 6 represents the XRD pattern of the preforms namely Fe-0.05C-0.70Mn, Fe-0.10C-0.70Mn, and Fe-0.15C-0.70Mn. The preform Fe-0.05%C-0.70%Mn which contained 0.05% of carbon shows the lowest intensity of Fe_3C and the preform Fe-0.10C-0.70Mn indicated the highest value of intensity of Fe_3C among the preforms tested. Therefore it has been confirmed that, the mechanical properties will be more in the preform Fe-0.10C-0.70Mn than all other.

C. Effect of instantaneous strain hardening index (n_i) on the mean stress (σ_m)

As shown in Figure 7, represents the variation of the instantaneous strain hardening index (n_i) with respect to the mean stress (σ_m) exhibits three stages. In stage – 1, represented in the figure, the instantaneous strain hardening index (n_i) value steeply increased with a very little increased mean stress. This was because of the initial resistance offered by the matrix material for deformation. In stage – 2, the deformation process overcame the resistance of matrix material and the material plastically flowed in to the pores. Now the value of mean stress was increased considerably with decreased instantaneous strain hardening index. This was the domination of geometric work-hardening with less increase of matrix work hardening. After appropriate filling of pores, again the matrix work-hardening came in to play. It is represented in stage – 3. This process continued until the initial crack appeared in the lateral periphery of the preform. The preform Fe-0.10%C-0.70%Mn achieved maximum instantaneous strain hardening index (n_i) in stage – 1 and in stage – 3 because of the content of more iron carbide and high initial relative density. The instantaneous strain hardening index (n_i) value of all the tested preforms were showed below 0.5. This result was in consistent agreement with the study carried out by others [15].

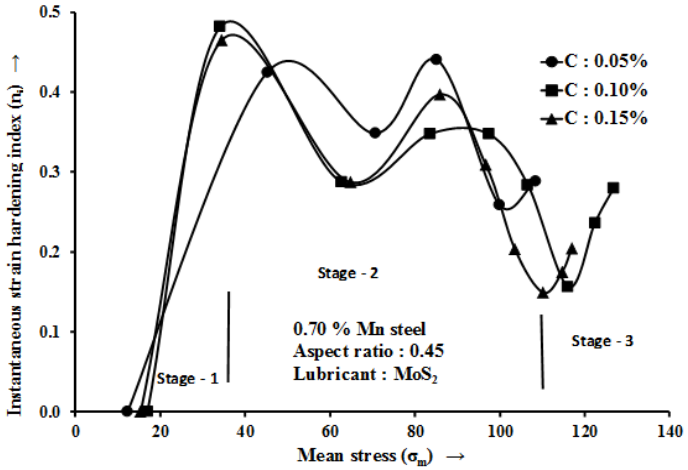


Fig. 7 The variation of the instantaneous strain hardening index (n_i) with respect to the mean stress (σ_m) with different carbon content of the Fe-C-0.70%Mn for the aspect ratio 0.45.

D. Effect of instantaneous strength coefficient (k_i) on mean stress (σ_m)

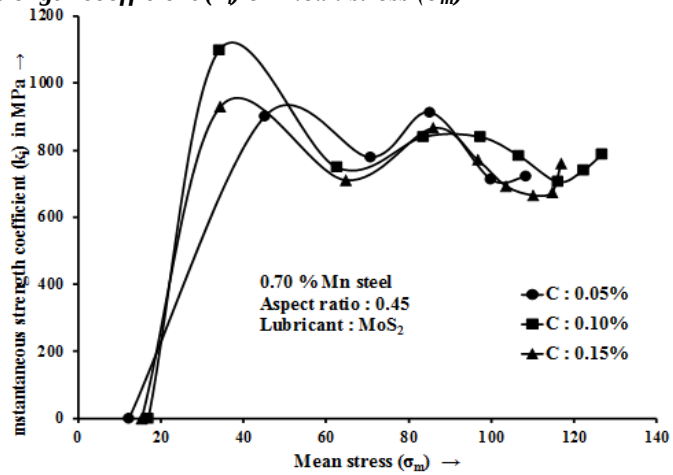


Fig. 8. The variation of the instantaneous strength coefficient (k_i) with respect to mean stress (σ_m) for Fe-C-0.7%Mn preforms with different carbon content for the aspect ratio 0.45.

The relation of instantaneous strength coefficient (*ki*) on the mean stress (σ_m) for Fe-C-0.7%Mn preforms was described in Figure 8. The formation of curves formed three stages as the previous curves. These results of the curves were in good agreement with the findings of the other author [12]. From the formation of the curves, it was found that, the preform Fe-0.10%C-0.70%Mn shows maximum value of instantaneous strength coefficient at the end of stage – 1 and stage – 3. The presents of more iron carbide was the reason for the increased value of instantaneous strength coefficient of the preform Fe-0.10%C-0.70%Mn. The preform Fe-0.05%C-0.70%Mn positioned in the last because of least content of carbon among the others.

E. Effect of formability stress index (β_σ) on axial strain (ε_z)

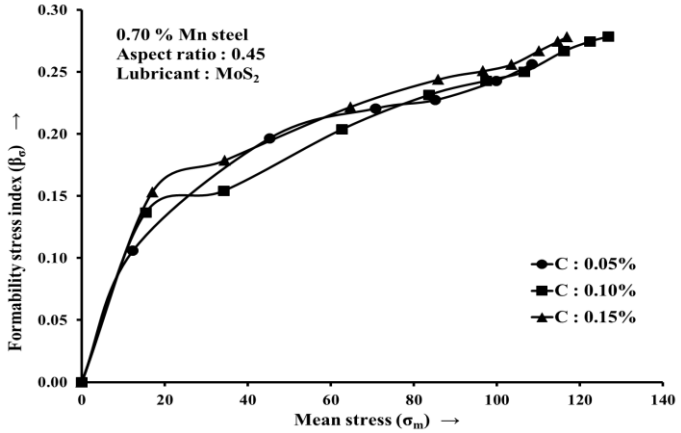


Fig. 9 The variation of the formability stress index (β_σ) with respect to mean stress (σ_m) with different carbon content of the Fe-C-0.70%Mn steel for the aspect ratio 0.45.

Figure 9 represents the relation between the formability stress index (β_σ) and the mean stress (σ_m) for the metal matrix composite preform Fe–C–0.70%Mn with variation in carbon as 0.05, 0.10 and 0.15%. The formation of curves had indicated three stages. In general, at the cold up-setting process, the formability stress index was increased rapidly in stage – 1 because of the resistance of the matrix material. During stage-2, due to the continuous process of deformation, higher amount of geometric work-hardening took place because of the closing of more pores by plastic flowing metal into the pores, which accelerated the reduction in the volume and thereby increasing the relative density. In the stage -3, since almost all the pores were filled, the resisting area was increased. Now, the lateral bulging was increased considerably and the matrix work hardening initiated once again until the creak. The higher initial density preform Fe-0.10%C-0.70%Mn has showed the maximum formability stress index value. These results are good in agreement with the findings of the above author [12].

TABLE 3. THE MAXIMUM VALUE OF FORMABILITY PARAMETERS OF THE PREFORMS AT THE DEFORMATION TEST.

Sl. No.	Preform C%	(σm) MPa.	(ni)	(ki)	(βσ)
1	0.05%C	108.42	0.441	913.04	0.2564
2	0.10%C	126.79	0.482	1099.0	0.2785
3	0.15%C	116.92	0.465	930.15	0.2781

Table 3 represents the maximum values of formability parameters of the specimens of three different carbon content preforms as 0.05%, 0.10% and 0.15% with common content of 0.70%Mn. The peak formability stress index value (0.2785) was achieved by the preform Fe-0.10%C-0.70%Mn which had the highest initial relative density. The maximum value of formability stress index was below 0.30 for any combination of iron and carbon content of tested P/M steel preforms.

V. CONCLUSION

The following conclusions were established from the critical analysis on deformation analysis of the Fe–C–Mn composite preform for their formability and work-hardening behaviour.

1. In the deformation process, the formation of the curves was in three stages. In the stage – 1, the matrix material exposed higher resistance against deformation so the matrix work hardening was identified. In stage – 2, the preforms underwent geometrical work hardening because of metal flow in to the pores. In stage -3, once again a matrix work hardening was noted due to the pores filling to the maximum extent.
2. The instantaneous strain-hardening index (n_i) and instantaneous strength coefficient (k_i) values were increased rapidly to its peak at very low mean stress values. Then the values were decreased up to the maximum pore closing of matrix material and again a increased was identified before the initial fracture.
3. Among the iron-based sintered powder metallurgy preforms tested by having different carbon and common manganese content, Fe–0.10C–0.70Mn Preform expressed as having better formability behaviour. Initial fractional theoretical relative density, less empty space in pores and greater presence of iron carbide (Fe_3C) were the established reasons.

REFERENCE

[1] D.R. Kumar, C. Loganathan and R. Narayanasamy, "Effect of glass in aluminum matrix on workability and strain hardening behavior of powder metallurgy composite" Materials and Design vol.32, pp.2413–2422, 2011
[2] R. Chandramouli, T.K. Kandavel, D. Shanmugasundaram and T. Ashok Kumar, "Deformation, densification, and corrosion studies of sintered powder metallurgy plain carbon steel preforms" Materials and Design Vol. 28, pp. 2260–2264, 2007
[3] N. Selvakumar, A.P. Mohan Raj and R. Narayanasamy, "Experimental investigation on workability and strain hardening behaviour of Fe-C-0.5Mn sintered composites" Materials and Design Vol. 41, pp. 349-357, 2012
[4] A. Simchi and Pohl H. "Effects of laser sintering processing parameters on the microstructure and densification of iron powder" Mater. Sci. Eng. A, Vol. 383, pp. 191-200, 2004
[5] Ding Hao, Ding Hua, Qiu Chun-in, Tang Zheng-You Zeng Jian-Min and Yang Ping et al. 'Formability of trip/twip steel containing manganese of 18.8%" J Iron Steel Res. Int., Vol. 18(1), pp. 36-40, 2011
[6] Schilke Martin, Ahistrom John and Karlsson Birger, "Low cycle fatigue and deformation behaviour of austenitic manganese steel in rolled and in as-cast conditions" Proc. Eng. Vol. 2(1), pp. 623-628, 2010
[7] M. Nadezda, S. Talijana, Dusan, D. Trifunovic and Dejan, "The influence of different iron powders on the friction properties of sintered friction materials based on iron" Materials Letters, Vol. 46, pp. 255-260, 2000
[8] A.P. Mohan Raj and N. Selvakumar, "Deformation behaviour of sintered Fe-C-Mn composite during cold upset forming" Materials and manufacturing process, Vol. 26(11) pp. 1388-1392, 2011
[9] M. Abdel-Rahman and MN. El-Sheikh MN, "Workability in forging of powder metallurgy compacts" J Mater Process Technol. Vol. 54, pp. 97–102, 1995
[10] K.A. Kuhn and C.L. Downey, "Material behaviour in powder preform forging" Trans ASME Eng Mater Technol. Vol. 95, pp. 41–6, 1973
[11] Dieter GE. Mechanical metallurgy. New York: McGraw-Hill; 1988.

[12] A.P. Mohan Raj, N. Selvakumar, R. Narayanasamy and C. Kailasanathan, 'Experimental investigation on workability and strain hardening behaviour of Fe-C-Mn sintered composites with different percentage of carbon and manganese content" Materials and Design, Vol. 49, pp. 791-801, 2013

[13] MPIF standard 42. Determination of density of compacted or sintered metal powder products. Metal Powder Industries Federation; 1977.

[14] A. Rajesh Kannan, K.S. Pandey and S.Shanmugam, "Some investigation on the cold deformation behaviour of sintered iron–0.8% carbon alloy powder preforms". J. Mater. Process. Technol. Vol. 203, pp. 542–547, 2008

[15] R. Narayanasamy, N. Selvakumar and K.S. Pandey. "Phenomenon of instantaneous strain hardening behaviour of sintered Al–Fe composite preforms during cold axial forming". Mater Des, Vol. 28, pp,1358–1363, 2007

