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Influence of carbon content on Workability and Density ratio of Sintered Iron Based Composites

A.P. Mohan Raj[1], C. Kailasanathan[2]*, P.Seenikannan[2]

[1]Narayanaguru College of Engineering, Manchalamoodu - 629151, Tamil nadu, India.
[2]Department of Mechanical Engineering, Sethu Institute of Technology, Kariyapatti-626115, Tamilnadu, India.

*Corres.author: uthrakailas@yahoo.co.in. Phone: 9655642261,Office – 04566308001

Abstract: Cold upsetting experiments were carried out on sintered Fe-C-Mn. P/M preforms in order to investigate their microstructure, workability and density ratio features at uni-axial stress state condition. Preforms with two different initial aspect ratios (0.45 and 0.60) and each aspect ratio with two different carbon contents (0.05 and 0.15%) with a common percentage of manganese of 2.0% and the rest was iron (base element) were prepared. The effect of manganese and carbon on the iron-based composite has been investigated thoroughly by using MoS_2 as a surface lubricant. Cold deformation experiments were conducted by incremental deformation process by applying load in steps of 50 kN until fine cracks appeared on its free surface. Initially the powders were milled in a high energy ball mill and sintered in an electric muffle furnace at 1050 ± 5°. The compacting pressure applied was 1200 MPa. In this present investigation, the effect of aspect ratio, carbon content, microstructure and initial preform density on stresses, strains and workability index was found and established.
Keywords: Cold upsetting, Sintering, Compaction, Microstructure, Uniaxial compression.

1. Introduction

Powder Metallurgy (P/M) process has been widely used for manufacturing parts due to their properties like material utilization, shape complexity, near-net shape parts, dimensional control and lower cost for high volume production of complicated components among others. However, compared to dense metal, plastic deformation of sintered powder preforms involves additional complications due to volume fraction of voids in the preform [1]. Kuhn and Downey [2] studied the basic deformation behavior of sintered iron powder by conducting a simple uni-axial compressing test and proposed a generalized yield criterion for sintered powder.

In a uni-axial stress state of compression, the load bearing cross-sectional area increases due to the reduction in the porosity level, which in turn increases the stress required for further deformation, resulting in the presence of strain and work-hardening behavior. A porous material would experience the usual strain or work-hardening characteristics as well as geometrical work hardening [3,5]. Since the preforms were P/M materials, they were under consideration as porous.

Workability is the term used to assess the ability of a material to hold up the induced internal stresses of forming before the splitting of material occurs. It is a complicated technological concept that depends not only the material, but also the various process parameters such as stress, strain rate, temperature and friction [6,8]. Abdel-Rahman and El-Sheikh [9] investigated the effect of relative density on the forming limit of P/M compacts in upsetting

The present report studied a three element powder composite in sub-micron dimension, which was reported rarely by other researchers. This composite (Fe-C-Mn) may have been used for manufacturing heat resistant brake drum and bearing due to its hardness, rigidity and porous nature. In this paper, an investigation into the workability index of P/M specimen against axial strain, density ratio, microstructure and XRD analysis were carried out.

2. Experimental details

2.1. Specimen preparation

Atomized iron powder of 99.79% purity was the baes element. The other elements of Carbon and Manganese were purchased as laboratory grade with 99.9% purity. The particle size of powder elements was approx. 30 µm. The composite powders were mixed on weight basis in calculated proportions (Mn: 2.0 %, C: (0.05and 0.15%) and rest was Fe. The composite powder was milled for 10 hours in a high energy ball mill (Fritsch- Pulverisette - 6), Toluene was used as a liquid process-wetting agent.

(a) **(b)** **(c)**

Fig1. (a) SEM photograph of Fe-C-Mn composite powder (magnification 1mm×500) (b) after compaction (c) after sintering

Compacts of 20 mm diameter with 9 mm height (aspect ratio 0.45) and 12.0 mm height (aspect ratio 0.60) were prepared. The carbon content was varied by 0.05% and 0.15% for each aspect ratio with a common manganese content of 2.0 % and the rest was iron. The compacts were prepared on a Universal Testing Machine of 1.0 MN capacity using a suitable die, punch and butt at a common compacting pressure of 1200 MPa. Molybdenum disulphide (MoS2) was used to lubricate the punch, die and the butt, while preparing the compacts.

These compacts were ceramic coated to prevent oxidization from the atmosphere for the sintering operation. The sintering was carried in an electric muffle furnace at 1050 ± 5° C for a holding period of 1 hour. As soon as the holding period was completed, the sintered preforms were allowed to cool inside the furnace itself to reach the room temperature. After the completion of total sintering process, the preforms were cleaned by using a fine wire brush.

2.2. Cold deformation experiments

Initialy the preforms were measured out for their height, diameters, and densities. The deformation being carried out between the two flat anvils hardened to 60 HRc and tempered to 46 HRc of a 3000 KN capacity compressive testing machine. When the P/M parts were compressed, height reduction as well as bulging at its surface happened. The average density was increased. All the preforms were subjected to cold uni-axial stress state of compression test with an incremental compressive loading in steps of 50 KN until the appearance of visible cracks on the free surface. In all the compression testing processes, Molybdenum di Sulphide (MoS_2) was used as a lubricant for all mating surfaces. Immediately after the completion of each step of loading, the height, the contact diameters at the top and bottom, the bulged diameter and the density were measured. The density measurements were carried out using the Archimedes principle.

3. Theoretical analyses

According to Abdel-Rahman and El-Sheikh [9] for uniaxial stress state condition,

$$\sigma_z = -\sigma_{eff}, \text{ and } \sigma_r = \sigma_\theta = 0 \qquad (1)$$

where σ_{eff} is the effective stress, σ_r is the radial stress. Once the fracture is initiated, the fracture strain is the same as the effective strain. It is denoted by $\varepsilon_{eff} = \ln(h_0/h_f)$ (2)

and mean or hydrostatic stress, $\sigma_m = \left(\frac{\sigma_z}{3}\right)$ (3)

Further, Vujovic and Shabaik [10] proposed a parameter called a formability or workability index (β) given by,

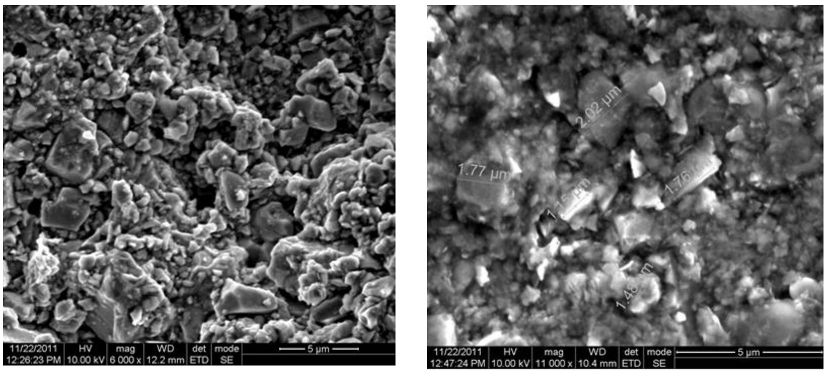
$$\beta = \left(\frac{3\sigma_m}{\sigma_{eff}}\right) \quad (4)$$

According to Selvakumar et al. [11], the other parameters are also given below

1. Axial stress $\sigma_z = \frac{Load}{Contactsurfacearea}$ (5)
2. Axial strain $\varepsilon_z = \ln(h_0/h_f)$ (6)
3. Hoop strain based on contact and bulged diameters $\varepsilon_\theta = \left(\frac{2D_b^2 + D_c^2}{D_0^2}\right)$ (7)
4. Fractional theoretical density ratio $\left(\frac{\rho_f}{\rho_{th}}\right) = \left(\frac{\rho_0}{\rho_{th}}\right)\exp(\varepsilon_z - \varepsilon_\theta)$ (8)

4. Results and discussion

4.1 Microstructure investigation



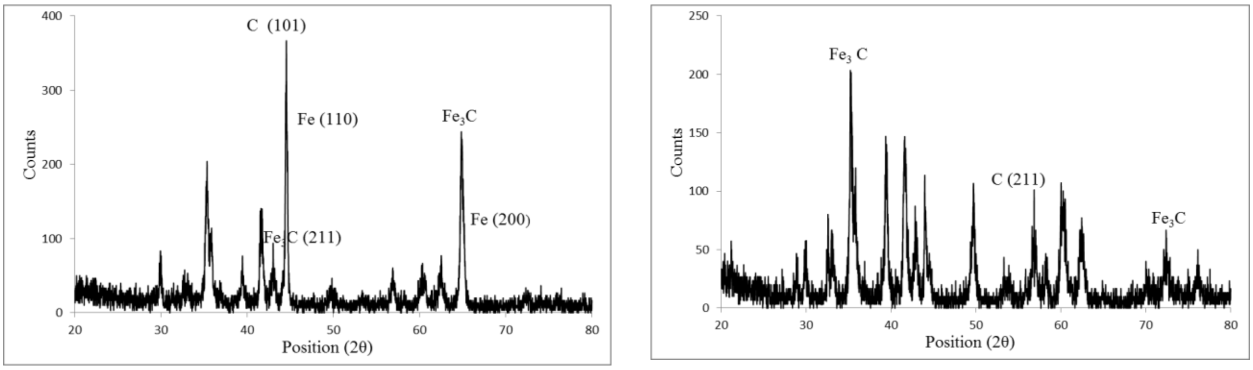
(a) (b)

Fig 2. HRSEM images of the preforms after sintering (a) Fe-0.15C-2.0Mn (magnification 1mm×6000) (b) Fe-0.05C-2.0Mn (magnification 1mm×11000)

Figur 2 represents the HRSEM image of the Fe–C–Mn composite sintered preforms having different carbon content namely 0.05% and 0.15% and a common content of manganese of 2.0 %. The microstructure of sintered Fe–0.05C–2.0Mn steel contains a more amount of pores than the preform which contains 0.15% carbon. Here, the compaction pressure was maintained as a constant value of 1.2 GPa for all compacts. It has been further observed that as the carbon content increases, the pore size decreases therefore the density increases for the same manganese content 2.0 %. This is because few of carbon go into the empty space (pores) react with the manganese and iron and thus form iron/manganese carbide.

Since the quantity of iron is more in the Fe–C–Mn preforms, the Fe_3C compound generally provides significant amount of strength to the preforms and obtains the ultimate in intensity in the preform Fe-0.15C-2.0Mn. Other compounds like manganese carbide are unable to provide high impact on the strength of preform since their quantity is very low. Figure 3 represents the XRD pattern of the preforms containing iron with 2.0 % manganese and different carbon content namely 0.05% and 0.15%. There are two peaks obtained at 44.671 and 64.984 (2Ө value) for 0.05 % carbon content preform and the preform which contains 0.15% carbon shows two peak values at 35.317 and 72.434 (2Ө value) for Fe_3C constituent and is demonstrated in Figure 3(b). The intensity of Fe_3C is higher in the 0.15% C preform and shows better strength than the preform having 0.05% of carbon.

4.2 XRD analysis

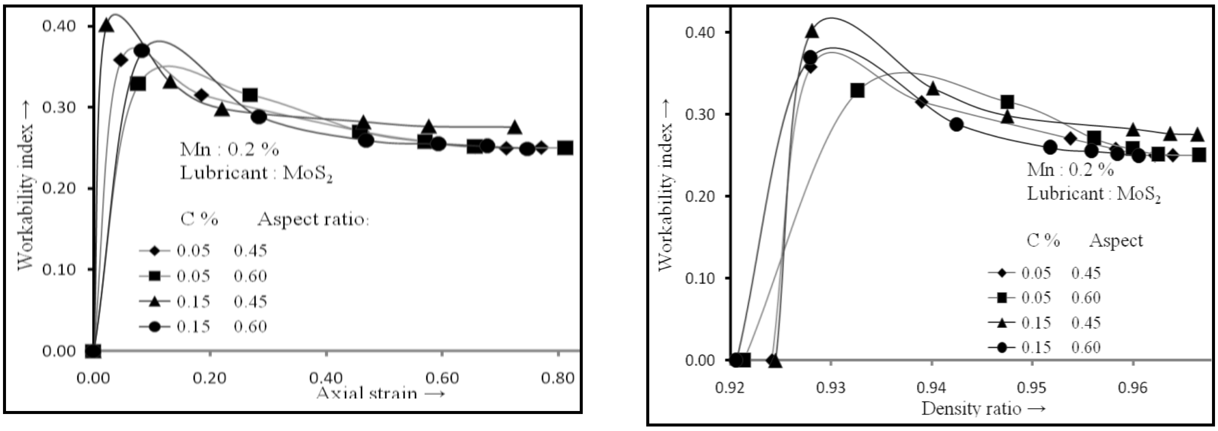


(a) (b)

Fig 3. XRD pattern of preforms (a) Fe - C 0.05- Mn 2.0 and (b) Fe - C 0.15- Mn 2.0

4.3 The relationship between density ratio (ρf /ρth) and workability index (β)

Figure 4 has been drawn to establish the relationship between the axial strain and density ratio with workability index (β) for sintered P/M preforms during cold axial deformation. The nature of the curves implies that, the workability was very high at the initial stage and then decreased to some extent, followed by very slow decrease with respect to the axial strain irrespective of the carbon content and aspect ratio. Higher initial density, higher carbon content and lower value of aspect ratio preforms show the higher value of workability index.



(a) (b)

Fig 4. The relationship between workability index (β) with (a) axial strain (ε_z) and (b) density ratio (ρf /ρth)

Figure 4 (b) shows that the same aspect ratio preforms of 0.45 and 0.60 secured almost the same density ratio even though the preforms were provided with different carbon content of 0.05% and 0.15%. It was also established that the stress formability (workability) index increases with increase in initial preform fractional theoretical density and lower aspect ratio. The first stage of curve represents the matrix work hardening and the third stage represents the geometrical work hardening. The peak of curve represents where all the pores nearly filled by flow of material into it at the time of comperession.

4.6. Conclusions

The basic conclusions that can be drawn from the present investigation are as follows:

- The stress formability (workability) index increases with increase in carbon content.
- For same carbon content, the preforms having low aspect ratio(0.45) show higher workability index than the higher aspect ratio (0.60) preforms.
- The deformation analysis shows that, at the initial stage of loading, the preforms attainted high amount of workability and with further loading it decreased suddenly to a specific stage, then followed by slow decreasing trend until the initial creak was formed.
- The carbon content increases, the pore size decreases therefore the density increases. This is because few of carbon go into the empty space (pores) react with the manganese and iron and thus form iron/manganese carbide.
- More amount of Fe3C formed in higher carbon content preforms. Fe3C gives more strength to preforms.

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