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Processing of Structural Components from High Carbon Content Rapidly Solidified Alloyed Ferrous Powders

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Abstract

Water atomization technique was adopted to produce High carbon content Rapidly Solidified alloyed ferrous powders. Initially the powders were annealed in presence of hydrogen at 700°C. They showed very poor compressibility. The compressibility got increased when the powders were annealed at 900°C due to surface decarburization. The advantages obtained due to rapid solidification also remained intact inside the powders. The powders were compacted at different pressures ranging from 300MPa to 700MPa. The compacts were sintered at three different temperatures like 720°C, 850°C and 1000°C.It is interesting to note here that growth instead of shrinkage was observed at all sintering temperatures. The hardness of sample compacted at 700MPa and sintered at 1000°C was found to be 48HRC. Here presence of fine ferrite-carbides (2-3μm) in fine ferrite matrix(3-4μm) in the sintered compacts helped in producing wear resistant structural components.

INTRODUCTION

Various types of wear resistant materials are traditionally manufactured from hard carbide materials like SiC, VC, WC, TiC etc. However manufacturing of such materials by casting, forging, cutting etc. is very difficult as well as expensive. In order to overcome this, continuous efforts are being put in to find out low cost materials and new processing techniques. In the recent days Rapid Solidification (RS) has emerged as a vital processing technique to bring structural changes in various low cost materials leading to excellent mechanical properties.

From the work of Sherby and co-workers [1-6] followed by other investigators [7-9] it has already been established that high carbon content ferrous alloys, carbon content ranging from 1.6% to 5.25%, can be produced by different methods of rapid solidification techniques. Again very fine grained equiaxed spheroidized iron carbibes(Fe_3C) in the range of 0.2- 0.5μm and finer ferrite grains in the range of 1-2μm can be obtained in such materials by adopting proper thermo mechanical consolidation routes. These structurally modified materials can deform superplastically at low strain rate and at low ambient temperature to produce various net shaped engineering products [4]. This fine grained powder processed material can have very good mechanical properties like 1000 MPa yield strength and around 20% ductility at room temperature. By special heat treatment this fine grained material can be made very hard (65-68HRC) with 4300 MPa compressive fracture strength [1, 4]. It has become possible to join this fine grained material to ferrous based as well as non ferrous based solid materials to produce laminated composites [6]. In USA, such materials are used for making components for high performance applications [4].

More than 95% of powder metallurgy (PM) methods of manufacturing of machine components follows cold compaction and sintering method [10-12]. Researchers have extensively studied the cold compaction of low carbon content ferrous powders. However in the present investigation an attempt has been made to manufacture rapidly solidified high carbon content ferrous powders from wrought iron which was obtained from low cost sponge iron fines and to study their various characteristics. Again a cost effective compaction and sintering processing route is adopted to make use of these powders to manufacture high performance machine components.

EXPERIMENTAL PROCEDURE

Production of High carbon content rapidly solidified alloyed ferrous powders

Sponge iron fines got melted in an fabricated arc furnace and wrought iron was obtained. The wrought again got re-melted in an induction furnace with requisite amount of graphite and other additives like flux, Ferro- chrome, Ferro-silicon and Aluminium. Then it was water atomized to get high carbon content rapidly solidified alloyed ferrous powders. The powders below 100 mesh size were taken for further investigation. The powders were annealed at 700^0C for two hours in hydrogen atmosphere.

Characterization of powders

The powders were characterized in various ways. The chemical characteristics are given in Table-1 and Physical-Mechanical characteristics are given in Table-2.

Table 1: Chemical characteristics of High Carbon Content Rapidly Solidified Alloyed Ferrous powders in wt%

C	Al	Cr	Si	S	P	Fe
3.51	2.0	1.5	1.3	0.012	0.03	Balance

Table 2: Physical –Mechanical characteristics of High Carbon Content Rapidly Solidified Alloyed Ferrous powders

Apparent Density (gm/cm^3)	2.63
Flow rate (sec/50gm)	23
True Density (Pycnometric)(gm/cm^3)	7.3

Cold Compaction of Powders

The 700^{0}C hydrogen annealed powders were thoroughly blended with 1% Zinc stearate. Here Zinc stearate was used for surface lubrication of the powders. Double action die was used during the cold compaction of the powders. The die wall was also lubricated by zinc stearate. A Servo hydraulic Universal Testing Machine of 50 ton capacity, made by Blue Star India, was used for this purpose. During cold compaction of 700^{0}C annealed powders, it was observed that up to 700MPa the powders could not get compacted. Then it was proposed to increase the annealing temperature to 900^{0}C. The 900^{0}C annealed powders were cold compacted at various pressures ranging from 300MPa to 700MPa. The green densities(GD) were recorded using micrometer and a microbalance. The mean value of three measurements was recorded for each case .The green densities are presented in Fig.1 –Fig.3.

Sintering of Compacts

The sintering operation was carried out at three different temperatures like 720^{0}C, 850^{0}C and 1000^{0}C by using a tubular sintering furnace, manufactured by Therelek Furnaces Private Limited, for one hour in each case in hydrogen atmosphere. The sintered densities (SD)were measured and data were recorded following the same procedure as followed in the measurement of green densities. The data are again presented in Fig.1-Fig.3. Growth in sintered compacts was observed in all cases and Growth data are presented in Fig. 4.

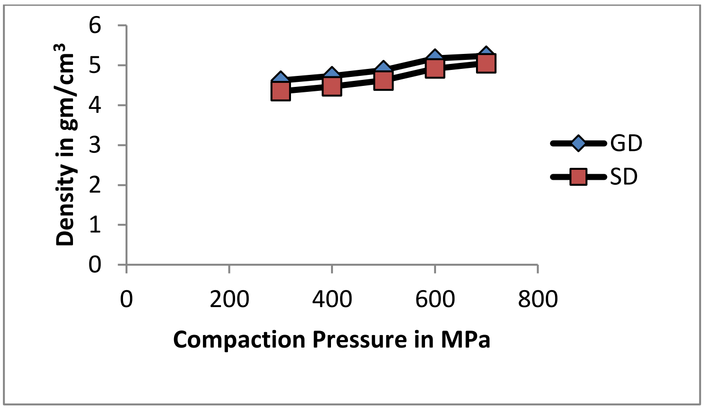

Figure 1: Green density and 720^0C sintered density of the processed material at various compaction pressures.

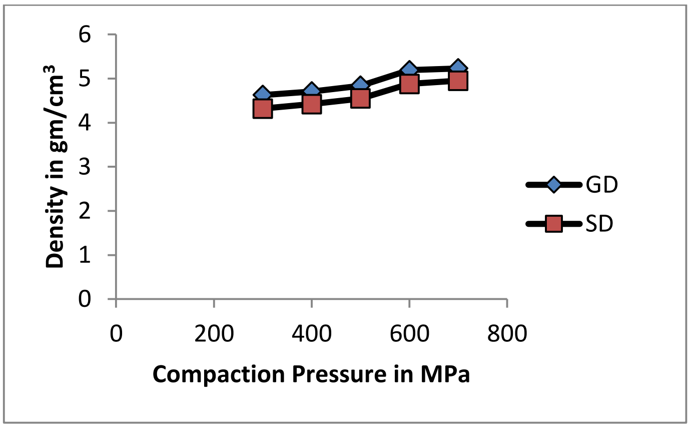

Figure 2: Green density and 850^0C sintered density of the processed material at various compaction pressures.

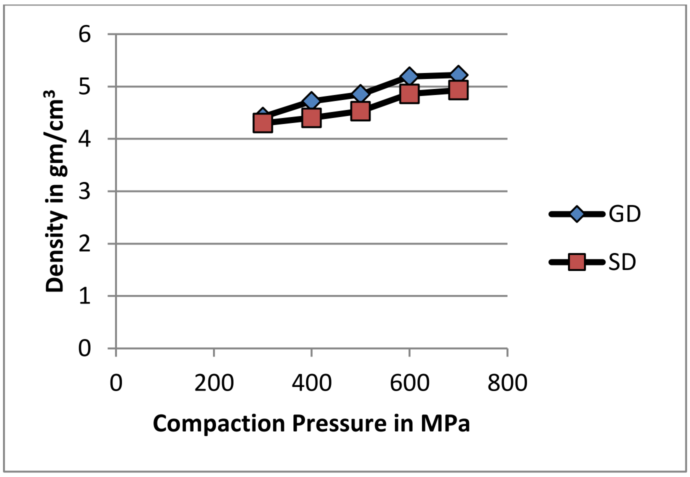

Figure 3: Green density and 1000^0C sintered density of the processed material at various compaction pressure

Hardness Studies

Rockwell hardness test on three different samples, which were compacted at 700MPa and sintered at 720^0C, 850^0C and 1000^0C, was conducted. The mean value of four measurements in each case is presented with standard error in Fig. 6.

Microstructural Analysis

SEM micrograph of the 700MPa compacted and 1000^0C sintered material was taken using JEOL 840 JSM Scanning Electron Microscope. This is presented in Fig.7.

RESULTS AND DISCUSSIONS

Characteristics of Powders

From table 1 is observed that 2.0wt% Al, 1.5wt% Cr and 1.3wt% Si are present in the high carbon content rapidly solidified alloyed ferrous powders. Addition of 1.5% of Cr acted as carbide stabiliser, 1.3wt % Si enhanced the A1 transformation temperature upto 1000^0C in the powders and Al in 2.0wt% helped in grain refinement. From table2 it is found that flow rate is 23 sec/50gm.This will provide very good flow of powders into die and is good for manufacturing machine parts through PM Process. The apparent density is a very useful parameter for designing the die and punch from which the apparent height for a given dimension of a product is calculated. For the above powders, it is found to be 2.63gm/cm^3, which is comparable with any quality powder of such kind.

Cold Compaction Studies

The acceptability of powders to powder metallurgy manufacturing industries largely depends upon their compaction characteristics. The 700°C annealed powders were taken first for the cold compaction study using double action die compaction process. Due to brittle nature of such powders the powders showed very poor compressibility. Here nearly 50% volume of iron carbides as well as complex carbides, which are quite brittle in nature, made the powders cold compacted poorly. But when the same powders were annealed at high temperature i.e. 900°C, some of the carbon from the powder surfaces was removed making the surfaces soft and internal part of the powders hard. Interestingly it was found that these surface decarburized powders did not indicate grain growth in the internal portions, which is shown in Fig. 5 . When this soft surface powders were again cold compacted showed improved compressibility. Here the cold compacts were quite stable for making them use for further sintering.

Sintering Studies

It is observed from Fig.1-Fig.3 that the green densities are higher than sintered densities for the corresponding compaction pressures for a particular sintering temperature. It is also very interesting to notice that growth instead of shrinkage is found at all sintering temperatures. One of the reasons of growth during sintering is due to pearlitic transformation of carbides, where the increase in volume takes place. As sintering temperature goes on increasing, the growth percentage goes on increasing. From Figure 4.8**,** it is also observed that for all sintering temperatures the growth percentage is higher when the compaction pressure is less.

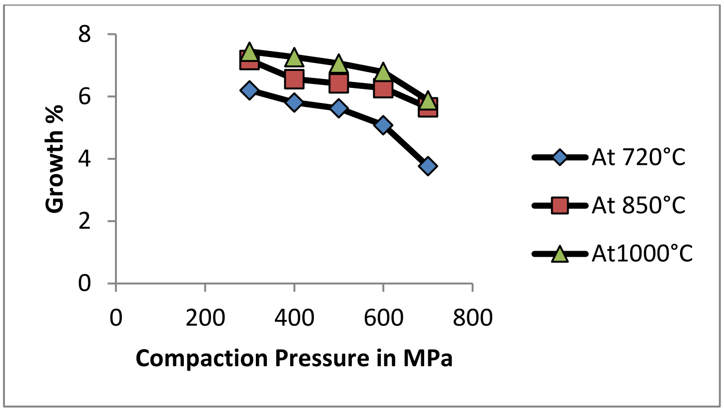

Figure 4: Growth % of the processed material at various sintering temperatures and compaction pressures.

Figure 5: SEM micrograph of surface decarburized high carbon content rapidly solidified alloyed ferrous powders

Hardness Studies

From Rockwell hardness test it is found that the sample which was sintered at 720^{0}C showed 34 HRC. The 850^0C sintered sample and the 1000^0C sintered sample showed 40 HRC and 48HRC respectively. This increase in hardness with temperature is probably because of better diffusion among particles of the processed materials.

Microstructural Analysis of the processed material

It is observed from Fig.7 that fine grains of ferrite-carbides (2-3µm) are present in fine ferrite matrix(3-4µm) in the sintered compacts. This very fine ferrite-carbide grains are attributing high hardness and good strength in the sintered materials making this wear resistant in nature.

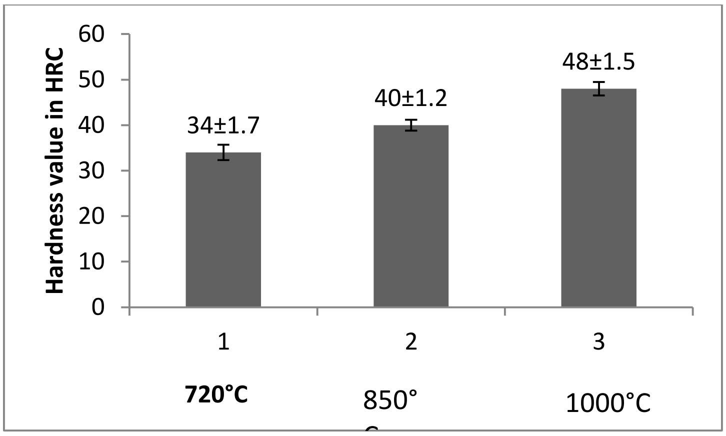

Figure6: Hardness values of processed materials compacted all at 700MPa and sintered at 720^0C,850^0C &1000^0C.

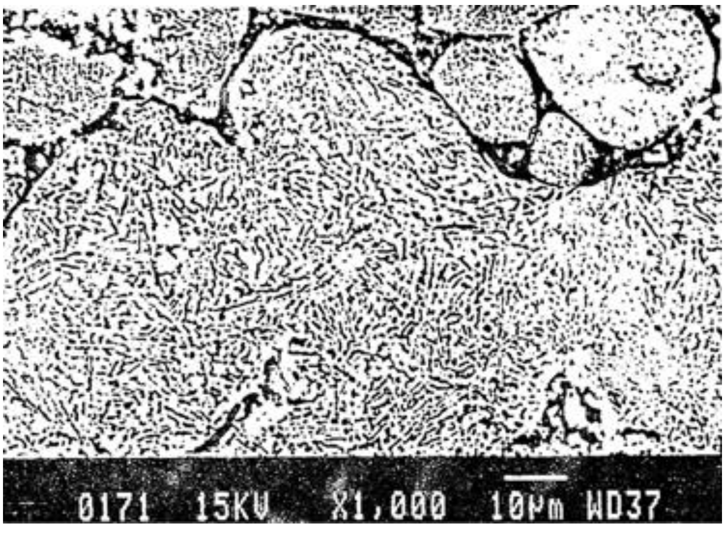

Figure7: SEM micrograph showing bonding among 700MPa compacted powder particles during sintering at 1000°C for one hour

CONCLUSIONS

1. Rapidly solidified high carbon content ferrous powders can be successfully manufactured from low cost sponge iron.
2. Completely incompressible high carbon content rapidly solidified ferrous powders became compressible by hydrogen annealing at 900^0C for one hour where the powder surfaces got decarburised and the core retained all the advantages of rapid solidification.
3. Growth instead of shrinkage was observed in sintered materials of cold compacted high carbon content rapidly solidified alloyed ferrous powders. As the sintering temperature went on increasing the growth percentage also went on increasing.
4. Samples compacted at 700 MPa and sintered at 1000^0C showed very fine grains of Fe_3C(2-3 µm) in fine ferrite matrix. This fine carbide grained sintered material can provide very good strength and wear resistance in it.
5. High growth provides high porosity in the rapidly solidified high carbon content ferrous powder sintered compacts. This is a quite useful parameter for manufacturing self lubricating bearings from this material by following simple powder metallurgy method.

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