American Journal of Engineering Research (AJER)
e-ISSN : 2320-0847 p-ISSN : 2320-0936
Volume-03, Issue-01, pp-280-291
www.ajer.org

Research Paper Open Access

Processing Of Fe - 1%Tic and Fe - 2%Tic Composites & Densification Behaviour Including Mechanical Properties

[1] Mrs. S. K. Pandey, [2] K. S. Pandey

[1] *Director, National Institute of Technology, Karaikaal, Puducherry, India.*
[2] *Professor, Department of Metallurgical and Materials Engineering, National Institute of Technology, Tiruchirappalli –620 0 15, Tamil Nadu, India.*

Abstract: - Present investigation pertains to evaluate the densification mechanism/s exhibiting the influence of initial preform geometries and the composition as well as to assess the mechanical properties of hot forged discs and square cross–section (~14mm x ~14mm) bars with an approximate lengths of 100±05mm at 1150 ± 10^{0}C of Fe -1%TiC and Fe–2.0%TiC systems. These compacts of the above systems were prepared on a 1.0MN capacity UTM, in the relative density range of 0.84 ± 0.01 by taking accurately pre-weighed powder blends for all aspect ratios, namely, 0.25, 0.50, 0.75 and 1.24 respectively by applying pressures in the range of 435 ± 20 M Pa using a suitable die, punch and the bottom insert. Ceramic coated compacts were sintered in an electric muffle furnace at 1150±10^{0}C for a period of 100 minutes. Sintered compacts of first three initial aspect ratios were axially hot upset forged to different height strains, whereas, the fourth one were hot forged to square cross - section bars of the above dimensions. Ten such bars were forged. Analysis of experimental data and the calculated parameters has shown that the lower aspect ratio preforms densified more rapidly compared to the higher aspect ratio preforms. Mechanical properties such as yield strength, tensile and fracture strengths including percentage elongation and percentage area reduction were obtained by conducting uniaxial tensile tests. Further homogenization step has improved the above properties. Thus, the present investigation opens up a new area of research.

Keywords: - *ceramic coating, Composite, densification, forged***,** properties, relative density,

I. INTRODUCTION

World wide popularity of Powder Metallurgy lies in the ability of this technique to produce complex metal shapes to exact dimensions at high rate and at extremely economical prices, and, thus, providing technical achievements to improve quality composite materials. These are produced with care from the various complex multi-phase powder particles via compaction, sintering and forging. Powder is compacted to desired shape of sufficient strength in lubricated dies after initial powder characterization. Lubrication reduces friction effects and provides strength and ease of ejection after pressing. Proper compacting at required pressures, the compacts attain sufficient strength to withstand ejection from the tools and subsequent handling unto the completion of sintering without breakage or damage. Thus sintering is an important step in powder metallurgy by which the required properties like strength, densification and dimensional controls are attained. Sintering temperature is normally taken in the range of 0.7 to 0.9 times of the absolute melting point of the highest melting major element taken in the investigation [1]. However, in order to achieve near full densification, a forging step is involved. This process gives the material its almost full strength, i.e., the material has attained near to full density [2].

Growing demand for materials to meet high temperature engineering applications present a serious problem to design engineers and to the metallurgist and thus a structural material which can be used at elevated temperatures is a boon today. This resulted in the quest for new materials, which demand greater efficiency in steam engines to aircraft and to missiles. The major requirements of such materials are high temperature resistance with increasing temperatures, high wear resistance, minimal oxidation and scaling rates [3]. Thus, structural materials can be divided in four classes namely, metals, ceramics, polymers and composites respectively. Composites, in general, consist of two or more separate materials combined in a macroscopic structural unit and are made from various combinations of metals, ceramic and polymers. Composites are generally used because they possess desirable properties which could not be achieved by either of the single constituents alone. Particles, flakes or fiber reinforcements are used. The matrix in the larger unit which holds the reinforcements and protects them from external damage transfers and distributes loads to fibers [4]. A composite is considered to be a multiphase material with a combination of properties. A strong material is relatively dense with increased strengths and stiffness but at a substantial loss of impact strength. Cermets are examples of ceramic – metal composites. Most common cermets is the cemented carbide which is composed of extremely hard particles of refractory carbide ceramic such as tungsten or titanium carbide embedded in a matrix of a metal. These composites are utilized as cutting tools for hardened steels. The hard carbide particles provide the cutting surface, but, being extremely hard, they are embedded in a matrix of a metal. They are as inclusions in a ductile metal matrix which isolates the carbide particles from one another and prevent particle to particle crack propagation [5]. However, the performance of composites depends upon the materials of which the constituents are composed, i.e., the form, structural arrangement of the constituents and the interaction among the constituents [4].

Iron based composites have been used widely spelled out structural applications in aircraft, missiles, engine components etc. With iron as a matrix imparts better high temperature softening resistance, a much better anti-seizure property and a higher wear resistance [6]. However, titanium carbide imparts wear resistance and hardness to the matrix phase. The electrical conductivity is found to be decreasing with increase in titanium carbide addition [7]. These tool materials with titanium carbide can be machined and are corrosion, oxidation and wear resistant. In addition, they are light weight and have high elastic modulus and vibration damping capacity. Apart from these titanium carbide is a cheap, easily available material with a high thermodynamic stability [8].

I.1 Manufacture of composites

Fabrication methods involve processing the metal either in a molten or in a solid state. Components can also be formed either by direct combination of matrix and the reinforcements or by the production of a precursor composite which in the form of composite wires, sheets, and laminates that are used to build up the component. Subsequently, the assemblage of piles must be consolidated and bonded in later processes.

In liquid – metal techniques, composites are prepared by infiltrating mats or fiber preforms with liquid metals or under carefully controlled conditions by physically mixing the reinforcements and the liquid metal together. A pseudo-liquid route is offered by plasma or flame spraying in which metal powder particles are heated above their melting point and are sprayed onto an array of fibers on a thin sheet of the same matrix metal. The resulting sheet of fiber-reinforced metal can then be stacked with other sheets and consolidated in subsequent operation. The simplest solid – state preparation route is to mix short fibers or particulates with metal powder. Alternatively, the metal can be coated onto the reinforcement by electrochemical or chemical vapour deposition method [9]. Few methods described in literature [9-13] for the manufacture of composites are liquid metal infiltration, squeeze casting, stir casting or compo-casting, consolidation and bonding methods, semi-solid slurry processing, co-spraying, press molding techniques, filament winding techniques, electrochemical co-deposition and powder metallurgy techniques.

Some of the processes adopted to produce particular composites include electro-deposition of zirconnia in a copper matrix [13], in-situ preparation of titanium base composites reinforced matrix by titanium boride single crystals by using P/M technique [14], manufacture of aramid fiber reinforced nylon-12 by dry powder impregnation [15], manufacture and properties of polyethylene homo-composites [16], combined process of coating and hybridizing for the fabrication of carbon – fibers reinforced aluminium matrix composites [17], manufacturing and applications of structural sand-witch components [18], silicon carbide particulates reinforced aluminium matrix composite rods and wires produced by new continuous casting route [19]. Pressure less sintering of and characterization of alumina (Al_2O_3) platelets reinforced barium-magnesium alumino-silicate glass composites [20] and carbon-fiber reinforcement on glass [21] are some of the examples quoted.

I.2 Porosities in Composites

Composites made by P/M route and conventional casting methods contained good amount of porosities and were not well eliminated and the distribution of reinforcements were not greatly improved. The presence of considerable amount of porosities means the occurrence of incomplete bonding between the matrix and the reinforcements, i.e., poor wetting. However, in the Pressure less state, a great enhancement in wetting between the melt and the reinforcements is feasible. Therefore, a prominent improvement in tensile properties can be obtained because of the interfacial bonding in this type of composite which renders it superior to conventional composites [22]. However, the porosities in these composites can be reduced considerably by mechanical working such as extrusion, swaging, forging and rolling etc. [23]. The plastic deformation contribution to the overall densification is a function of the deformation behaviour of the different components in the powder composites [25].

I.3 Mechanism of Deformation

Production of parts by conventional P/M route involves compaction and sintering which has a substantial fraction of voids which limit its use to less than heavy duty applications. One method to enhance properties of sintered materials involves deformation process which densifies and develops final desired shape. Powder preform forging is particularly attractive because it blends the cost and material saving advantages of conventional press and sinter powder compacts with the higher production rates and property enhancement due to forging which has enhanced the density. Investigation of densification of a porous material is facilitated by consideration of deformation of material element containing a void. It is well known that from the theory of plasticity analysis of a thick walled sphere that it is impossible to completely close a hole purely by the application of hydrostatic loading of a finite magnitude. However, the pressure (P) required for a plastic deformation of a sphere containing a hole is given by:

$$P = 2\sigma_o \ln (r_0/r_f) \quad \ldots\ldots\ldots (1)$$

Where "σ_o" is the flow stress of the material, "r_0" is the outside radius (equivalent to mean space between the voids), "r_f" is the hole radius (equivalent to void radius). It is clear that voids of larger diameter (large, r_f) requires less pressure for densification, but, for smaller void radius the pressure required is high to close down is unbounded. Under hydrostatic pressure, void simply changes size, but, not the shape as the pressure is equal in all direction [26]. Now, therefore, the pores play a role in limiting the mechanical properties is obvious. Voids act as sites for initiation of fractures and provide an easy path for crack propagation [27]. Hence, the elimination of pores in the preform by deformation processing is imperative for achievement of high performance properties [2]. In compacting metal powders, the total porosity of the compact decreases rapidly at first and then more and more slowly with increasing compacting pressure. The total porosity of a powder compact cannot be changed without affecting the pore size distribution (28).

Forging denotes a family of processes by which the plastic deformation of the work-piece is carried out by compressive forces. Forging is one of the oldest metal working processes known. Forging can be carried out at room temperature and is called cold working or at elevated temperatures called warm and hot forging depending upon the temperature. However, forging is classified as;

1. Open die forging, and,
2. Close die forging.

Open die forging generally involves placing a porous cylindrical work piece between the two flat die (platens) and reducing the height of the porous cylinder by compressing and this operation is also known as upsetting. Specimen can develop a barrel shape and this barreling is caused primarily by frictional forces at the die and the work-piece interfaces that oppose the outward flow of the materials and the pores at these interfaces. Barreling also occurs in upsetting the hot work pieces in between the flat, but, cool dies. The material at and near the interfaces cool rapidly, while the rest of the specimen is relatively hot. Since strength decreases with temperature, the ends of the specimen in contact with the die surfaces offer a greater resistance than do the free ends [2].

The theory of plasticity is applicable for conventional incompressible materials, whereas, to predict flow of a porous material, the simultaneous decrease of volume must be incorporated. Production forging of powder preforms is normally carried out in closed dies with the aim of achieving full density. However, upsetting between flat dies is applicable as a model for the initial stage of closed die forging until the lateral flow of the preform material forces against the die walls. The modes of initial material flow are an important consideration in the choice of preform and die geometries. Dead zones created during initial deformation in which densification lags behind other regions which are difficult to compact them later on when they are enclosed by a shell of denser and stronger material [24]. Comparison of forging from wrought bar stock production route, the forging of P/M preforms can be referred elsewhere [30 – 35]. Some Industrial applications of powder forging and the powder preform forging routes are shown in fig. 1 [29]. Some important literature on a number of automotive parts, e.g., diesel engine tappets, automotive valve caps, and certain soft magnetic parts are being produced by cold forging of P/M preforms. P/M structural parts finding their applications in automobiles, but, their use has rapidly spread into the fields of house hold appliances, farm and garden equipment, business machines, power tools etc. The present investigation has been undertaken because the steels which are recognized as the foundation of the engineering industry is susceptible to oxidation at high temperatures and corrodes under the hostile environment. Thus, with the new era of composites the present investigation is aimed at developing an iron based – titanium carbide dispersed composites for high temperature structural needs. The compositions chosen were Fe–1%TiC and Fe-2%TiC. Literature has shown that titanium carbide containing composites exhibited high hardness and ductility along with the good property of wear resistance. Possible area of applications is for engine wear resistant parts, tool and die making and high temperature furnace appliances [30-35].

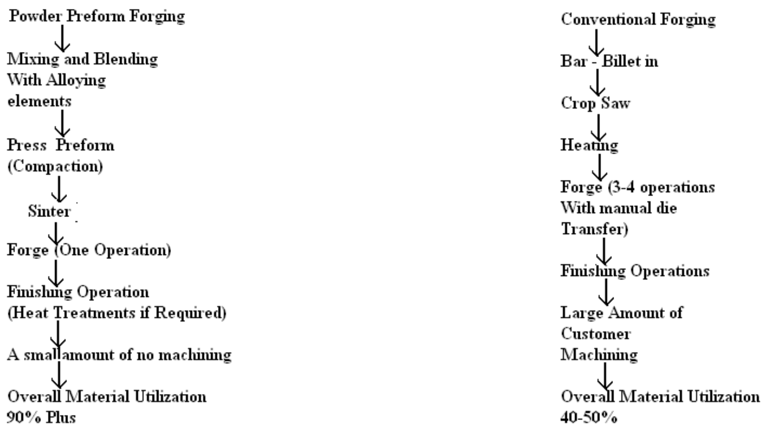


Figure 1 Powder and Conventional Forging Details [29]

II. EXPERIMENTAL DETAILS

Materials required and their characterization including sieve size analysis, apparent densities, flow rates, compressibility for iron, Fe - 1%TiC and Fe - 2%TiC were assessed. The compaction of powder blends, ceramic coating of compacts and subsequent sintering and forgings are detailed.

II.1 Materials Required

Material required were iron and titanium carbide powders, graphite powder of 3-5um for lubrication and linseed oil as quench ant for quenching after forging. Suitable die, punch and bottom insert were required for compacting powder blends of Fe-1%TiC and Fe-2%TiC respectively, ceramic coating, furnace for sintering the ceramic coated compacts, a suitable Chromel / Alumel thermocouple along with the temperature indicator cum – controller, a Universal Testing machine for compacting and Friction screw press for forging were also required. Atomized iron powder of -180µm was obtained from M/s Hoaganaes Corporation, Hyderabad, Andhra Pradesh, India. However, titanium carbide powder of -.37µm was procured from M/s. Ghrishma Speciality Powders, Mumbai, Maharashtra, India. Further, the graphite powder of 3-5um was obtained by courtesy, Ashby Inc., USA. Chemical purity of atomized iron powder was 99.63 per cent with remaining 0.37 per cent insoluble impurities.

II.2 Powder and Powder Blend Characterization

Since the main ingredient powder was iron its sieve size analysis was carried out and is reported in Table 1. However, the other properties such as apparent .densities, flow rates and compressibility were recorded. for iron powder, Fe-1%TiC and Fe-2%TiC powder blends and the same are reported in Table 2

Table 1: Sieve Size Analysis of Iron Powder

Wt. % Powder Retained	Sieve Size, µm									
	+150	+125	+106	+90	+75	+63	+53	+45	+37	-37
Wt.% Ret.	10.100	21.942	9.460	2.100	20.100	12.112	11.100	5.70	0.320	7.00
Cum. Wt.% Ret.	10.100	32.042	41.502	43.602	63.702	75.814	86.914	92.614	92.934	99.934

Table 2 Properties such as Apparent Density, Flow Rate and Compressibility of Iron, Fe – 1%TiC and Fe-2%TiC Blends

S. No.	Systems Selected	Apparent Density, g/cc	Flow Rate, S/50g. (by Hall Flow Meter)	Compressibility, g/cc, at a pressure of 400±10 M Pa
1.	Iron	2.961	26.151	6.594
2.	Fe- 1.0%TiC	2.897	20.151	6.550
3.	Fe-2.0%TiC	2.994	21.307	6.517

II.2 Powder Blend Preparation

In order to carry out the blending of the required amounts of iron and titanium carbide powders in two proportions by weight, a pot mill was used. Required amounts of iron and titanium carbide powders in two sets were taken and placed inside stainless steel pots and these pots were securely tightened on the mill after tightly closing their lids. Blending operation ensures uniform distribution of powder ingredients. In these two cases, the powder mixes to ball (10 – 15 mm diameters) ratio by weight was maintained at 1.2:1. After a run time of an hour, nearly 100g of powder mixes from each pot were taken out for the measurements of flow rates and apparent densities. Immediately after the completion of measurements, the powder mixes were returned back to their respective pots and the pots were securely fixed on the mill after tightening their lids, and, then the mill was operated again. This test has been repeated periodically after the lapse of every one hour. The pot mill was switched off, once the last three measurements for flow rates and apparent densities were consistent. Thus, the blending time of 24 hours was found to be ideal for both the systems.

II.3 Compaction of Iron and Powder Blends

Powder blends were compacted in compacting die of 26+0.1 mm diameter and a height of 140 mm with a wall thickness of 37mm. The punch height was 150 mm and its diameter was $26^{-0.1}$mm with a bottom insert of 20 mm height and $26^{-0.1}$ mm diameter. Thus the compact diameter was fixed to be $26^{-0.1}$mm and only

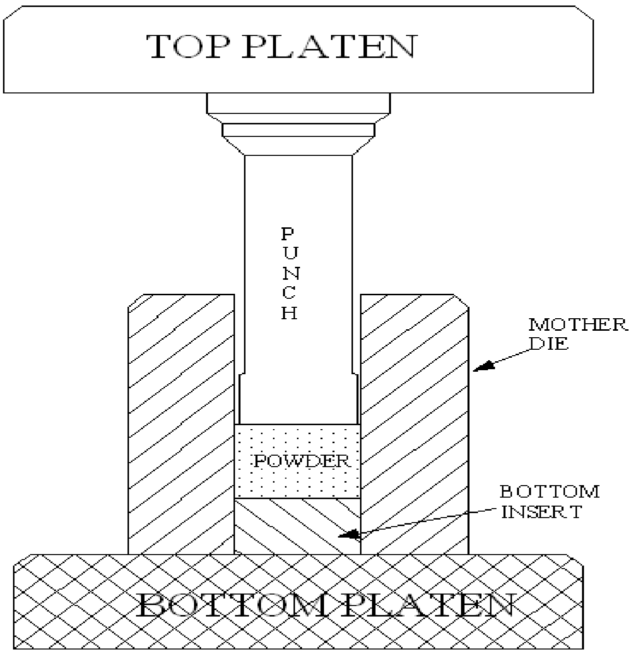


Figure 2 Schematic Diagram of compaction Assembly

option was to vary the height to get initial aspect ratios of the compacts as 0.25, 0.50, 0.75 and 1.24 respectively. This was attained by taking pre-weighed powder and applying controlled pressures in the range of 420±10 M Pa respectively for initial aspect ratios of 0.25, 0.50, 0.75 and 1.24 respectively. Thus the density was obtained in the range of 84±1 per cent of theoretical. An external lubricant, molybdenum-di-sulphide was used as a lubricant during compaction.

II.4 Ceramic Coating and Drying

The burrs on the compact edges were filed off. Indigenously developed ceramic coating was applied on the entire surfaces of the compacts of all compositions and all aspect ratios. These surface coated compacts were allowed to dry under ambient conditions for a period of sixteen hours. A second coat was applied on the already coated compacts in the direction 90^0 to the previous coating and this coating was once again allowed to dry for a further period of sixteen hours under the aforementioned conditions.

II. 5 Sintering of Ceramic Coated Compacts

Sintering process is an important step prior to forging. Therefore, sintering must result in a strong bond formation between the particles and thereby enhancing density and as a consequence of the same, the strength. Sintering, in general, is carried out in the range of 0.7–0.9 times the absolute melting point of the base component in a multi-component system. The ceramic coated and dried compacts were sintered at 1150610^0C for a period of ninety minutes in a Kanthal wound muffle furnace. However, preheating of the compacts was carried out at 600610^0 C for a period of 120 minutes so as to avoid bursting of compacts during sintering due to entrapped gaseous release. Chromel / Alumel thermocouple was used along with a temperature indicator cum controller. Prior to sintering operation, the compacts were kept in a ceramic tray of 180 mm length and 150 mm X 150 mm cross-section. This tray was kept in a square cross – section (200 mm x 200 mm) furnace chamber with a depth of 240 mm. Now after sintering schedule was over, the sintered compacts were ready to be forged.

II. 6 Hot Upset Forging to Discs and Square Cross-Section Bars

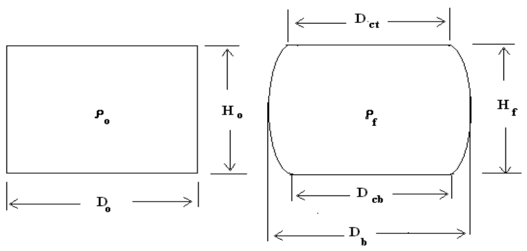
Sintered preforms were hot forged at 1150610^0C to various deformation levels on a friction screw press of 1.0 MN capacity using flat dies. Immediately after forging, the forged compacts were transferred to an oil bath (linseed oil bath) kept at room temperature to retain the forged structure and to avoid any oxidation after forging. This whole process of forging and transferring to oil bath took around 15 – 20 seconds. The sintered compacts with initial preform aspect ratios of 0.25, 0.50, and 0.75 respectively were axially hot forged to different height strains in order to enable evaluation of densification mechanisms. However, the cylindrical compacts of initial aspect ratio of 1.24 were hot upset forged from two sides to square cross – section (~14mm x 14mm) bars of 100±05 mm. These were used to evaluate the tensile properties.

II. 7 Removal of Residual Ceramic Coating

Residual ceramic coatings from the forged compacts were removed by mild grinding and manual filing then these specimens were smoothened using fine emery papers for measuring density and forged dimensions. This procedure of removing the residual ceramic coating was done uniformly to all forged compacts.

II. 8 Dimensional Measurements

Figure–3 shows the initial and the deformed sintered compacts. Dimensional measurements were made



(a) **(b)**

Figure 3 Initial (a) Sintered Preform, and, (b) Sintered, but, Forged Disc.

for initial height and initial diameter. In case of forged compacts, the dimensional measurements such as forged height, contact (top and bottom) diameters and the bulging diameter were carried out. From these measurements true height and true diameter strains were calculated along with the forged aspect ratios.

II.9 Densities of all forged compacts

Density Measurements were evaluated following Archimedes principle. Weight in air was taken on an electronic balance with a sensitivity of 10^{-4} g. A very thin, but, mild mustard oil film was applied on the entire surfaces of the forged compacts prior to measuring the weights in water so as to avoid the penetration of water during measuring the weight in water. The density was measured as:

$$\rho_f = W_{air} / (W_{air} - W_w) \times \text{Density of water} \quad \textbf{(2)}$$

Where, ρ_f is the forged density in g/cc, W_{air} is the weight of the forged compact in air and W_w is the weight of the forged compact in water.

II.10 Tensile Tests

Standard tensile test specimens were prepared from the square cross-section bars to be tested on a 2,000 Kg capacity Hounsfield Tensometer. While conducting the tensile tests observations are made on the elongation of the specimen and the area of cross section where necking started and grew up unto fracture. Tensile test is ultimately used for the following considerations.

1. fundamental mechanical properties assessment for the use in designing parts or components, and,
2. Establishes the basis for the selection of the values for engineering design Apart from the above, the fractured surfaces were used to obtain SEM fractographs to assess the mode of fracture.

III. RESULTS AND DISCUSSIONS

III.1 Compressibility Test Results

Compressibility of powder refers to the ability of the powders to be compacted under the application of load. However, the compressibility is a function of various parameters such as powder shape, size and their distribution. Moreover, it is also dependent on the inter particle friction. Once the die cavity is uniformly filled with the metal powders, it gives rise to certain packing density, but, some amount of pores is also formed. First densification occurs on the application of load through the punch, it sets the particle movement and rearrangements causing improved packing density. When the pressure is further increased the clean particles close together and adhere to each other [1]. The compressibility plots are drawn between the percentage fractional theoretical density and the applied pressure. These plots are shown in figs. 4(a) and 4(b) respectively. The observation of these plots indicate that as the compacting pressure is raised the compact density, too, has gone up. However, after certain load, the further application of load showed a flattening of these curves indicating the saturation of pore density inside the compact in agreement with others [9]. Figure 4(a) represents for Fe-1%TiC and 4(b) represents Fe-2%TiC composites.

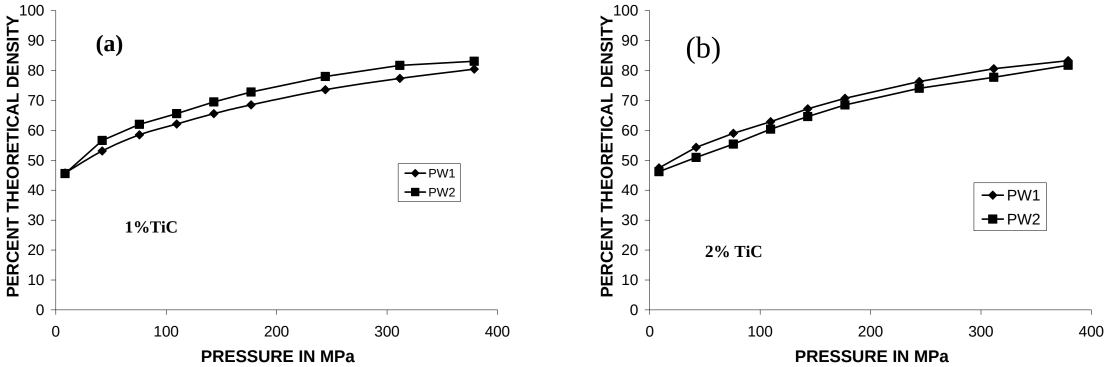


Figure 4 Compressibility Plots for Iron-Titanium Carbide Blends

III.2 Deformation and Densification

Figs. 5(a) and 5(b) have been drawn between the fractional theoretical density (ρ_f/ρ_{th}) and the true height strains (ln (Ho/Hf) for Fe-1%TiC and Fe-2%TiC composites during hot forging respectively. These plots indicate the influence of preform geometry on densification mode for a given percentage of titanium carbide addition. Examining these two figures 5(a) and 5(b), it is, observed that the rate of densification is comparatively steep in the beginning followed by a virtual steady state and ultimately at higher strain levels the curves exhibiting flattening pattern. Further observation shows that the preforms with lower initial aspect ratios have densified more rapidly than the higher initial aspect ratio preforms. This behaviour has been true irrespective of titanium carbide addition. This means that the preforms of initial aspect ratio of 0.25 always remained above the other two plots drawn for initial preform aspect ratio of 0.50 and 0.75 respectively. This behaviour is attributed to the fact that there is a rapid and uniform load transfer all across the deforming compact of 0.25 initial aspect ratio compared to the one with higher aspect ratio preforms. Due to mild damping effect in pore volumes (i.e., higher H/D ratios), higher order of inhomogeneity in deformation becomes the route cause for poor densification. In addition to this, the pores tending to move towards the free surfaces of the deforming preform coalesce just before reaching to the free surfaces and open out as cracks. While examining figs. 5(a) and 5(b), the common feature of these curves are that they exhibit similar characteristic nature, and, further these curves are found to correspond to a third order polynomial between dependent variable (ρ_f/ρ_{th}) and the independent variable ln (H_o/H_f) where, ln (H_o/H_f) = εh, ρ_f is the forged density and ρ_{th} is the theoretical density of the system. H_o is the initial height and H_f is the forged height. The third order polynomial to which these curves conform to is of the form:

$$(\rho_f/\rho_{th}) = A_0 + A_1\varepsilon h + A_2\varepsilon h^2 + A_3\varepsilon h^3 \text{ ……… (3)}$$

Where, 'A$_0$', 'A$_1$', 'A$_2$' and 'A'$_3$are empirically determined constants and are dependent upon the preform geometries and the compositions of the composite systems investigated. The values of 'A'$_1$ are in close vicinity of the initial preform density, and, therefore, do not contribute to densification. Whereas, 'A'$_1$ is always positive and, therefore, contributes to densification linearly while 'A'$_2$ possesses always negative value of low magnitude and hence moderates the densification in the final stages of densification little more effectively than does in the initial stages. The values of these constants are listed in Table 3. However, the value of 'A'$_3$ is mostly positive except in one case when 'A'$_3$ is negative then 'A'$_2$ is positive. Thus, they compensate for each other. Since the values of regression coefficient, 'R^2' for each aspect ratio is very much close to unity, and, therefore, the relationship given in (3) stands justified.

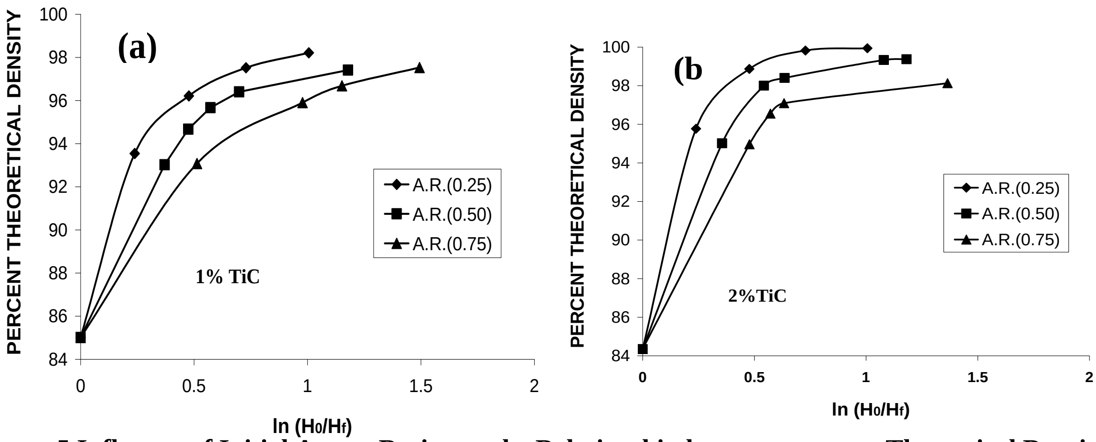


Figure 5 Influence of Initial Aspect Ratios on the Relationship between per cent Theoretical Density and the Height Strain

Table 3 Coefficients of 3rd Order Polynomial of the Form: $(\rho_f/\rho_{th}) = A_0+A_1\varepsilon_h+A_2\varepsilon_h^2+A_3\varepsilon_h^3$

Composition	Aspect Ratio	A_3	A_2	A_1	A_0	R^2
Fe-1%Tic	0.25	0.295	- 0.645	0.481	0.85	0.998
	0.50	0.075	-0.271	0.320	0.849	0.994
	0.75	0.072	-0.0245	0.289	0.850	0.999
Fe-2%Tic	0.25	0.428	-0.932	0.659	0.844	0.997
	0.50	0.269	-0.667	0.541	0.843	0.999
	0.75	-0.208	0.276	0.112	0.843	0.995

III.4 Relationship between True Diameter and True Height Strains

Figs. 6(a) and 6(b) are drawn between the true diameter and the true height strains for both the systems, i.e., Fe-1%TiC and Fe-2%TiC respectively. These two figs. reveal that all data points corresponding to each aspect ratio irrespective of the composition, remain below the theoretical line under ideal conditions, and, in the plastic region, the ideal value of Poisson's ratio would be 0.5, and, therefore, the theoretical line has the slope of 0.5. Since, all the data points remain below the theoretical line, confirming to the fact that the Poisson's ratio for porous materials in plastic deformation will always remain less than 0.5, meaning thereby, that the ratio of true diameter strain to true height strain (which of course, is the Poisson's ratio) can attain a value of 0.5 in the near vicinity of the theoretical density. Further, it is noticed that the curves corresponding to lower aspect ratio preforms are nearest to the theoretical line than the curves corresponding to higher aspect ratio preforms which goes to suggest that the Poisson's ratio is influenced by the geometry of the preforms as well as the compositions of the system investigated. Mathematically, it has been established that the curves shown in figs. 6(a) and 6(b) conform to a third order polynomial of the form:

$$\ln (D_f/D_0) = B_0 + B_1 \ln (H_0/H_f) + B_2 [\ln (H_0/H_f)]^2 + B_3 [\ln (H_0/H_f)]^3 \text{ --------------------- } (4)$$

Table 4 Coefficients of 3rd Order Polynomial between ln (D_f/D_o) and ln (H_o/H_f) For Fe-1%TiC and Fe-2%TiC Composite Steel during Hot Forging

Composition	Aspect Ratio	B_3	B_2	B_1	B_0	R^2
Fe-1%Tic	0.25	-1.1246	1.8009	-0.2133	-0.0017	0.999
	0.50	0.2892	0.6152	0.1575	-8E-05	0.9999
	0.75	0.1669	+0.5397	0.0427	-0.0002	0.9999
Fe-2%Tic	0.25	-0.853	1.342	-0.063	-0.008	0.971
	0.50	-0.461	0.948	-0.028	0	0.999
	0.75	-0.408	-1.066	-0.261	3E-05	0.998

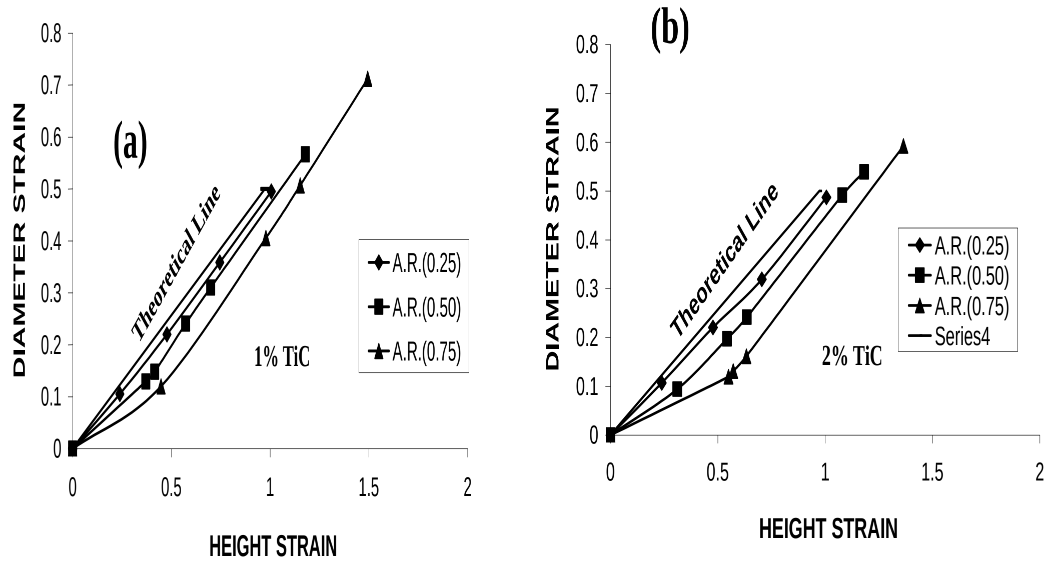


Figure 6 Influences of Initial Aspect Ratios on the Relationship between True Diameter and True Height Strains

Where, B_0, B_1, B_2, and B_3 are empirically determined constants and are found to depend upon the initial aspect ratios of the preforms and the compositions of the systems investigated. Further ln (D_f/D_o) is the true diameter strain ($€_d$) and ln (H_0/H_f) is the true height strain ($€_h$).

III. 5 Poisson's Ratio and Densification

Figs. 7(a) and 7(b) are drawn between the Poisson's ratio and the per cent theoretical density attained during hot forging of sintered preforms of Fe-1%TiC and Fe-2%TiC composites respectively. These plots also

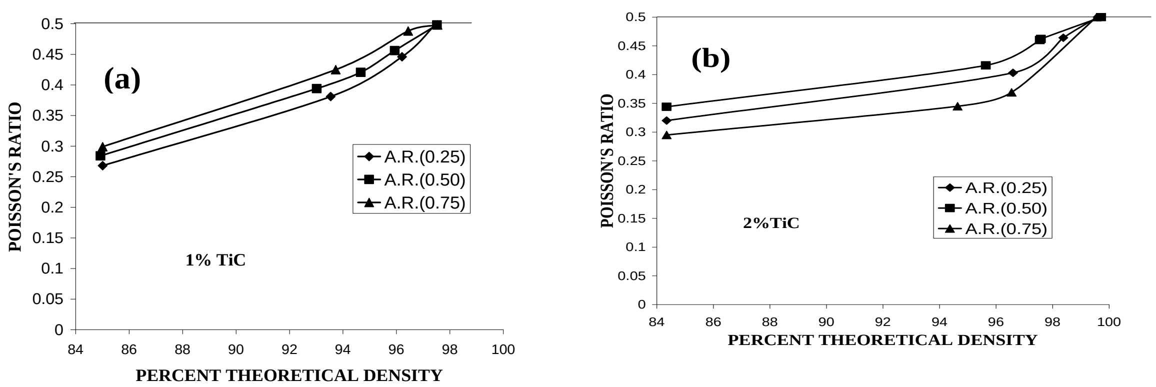


Figure 7 Influences of Initial Aspect Ratios on the Relationship between Poisson's Ratio and Per cent Theoretical Density

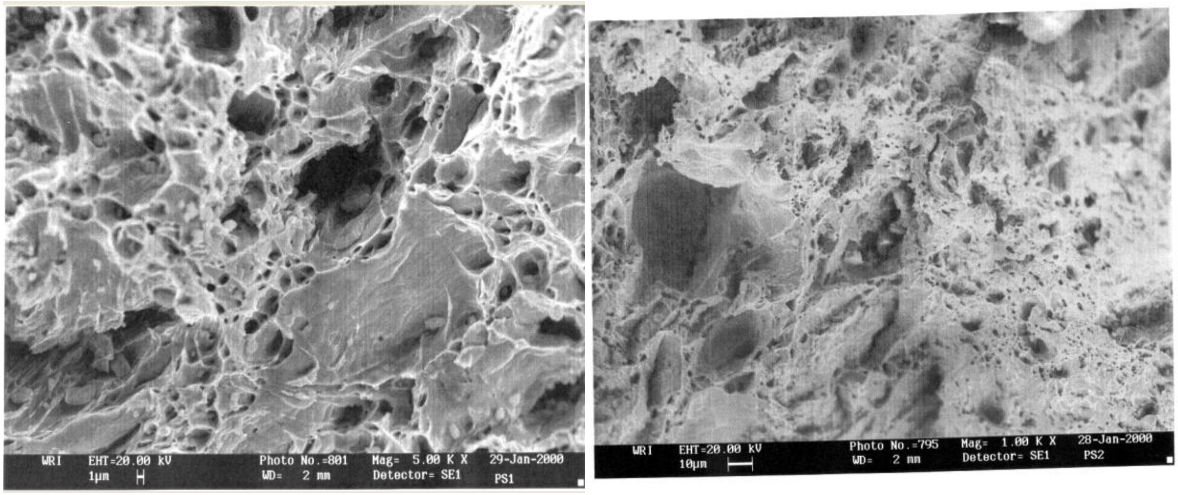
exhibit the influence of preform geometry on the Poisson's ratio variation with respect to attained densities. While examining these two figs. 7(a) and 7(b), it is, observed that the curves corresponding to lower aspect ratio preforms remained above the other two curves corresponding to higher aspect ratio preforms. This phenomenon is true irrespective of the compositions investigated. Apart from these, the curves in these two figs. 7(a) and 7(b) indicate the tendency to approach to a limiting value of Poisson's equaling to 0.5 in the near vicinity of the theoretical density. It is also observed that the nature of curves corresponding to higher aspect ratios tended to deviate compared to the lower aspect ratio preforms irrespective of the compositions. Therefore, this behaviour is attributed to the number of pores, their size and its distribution apart from their total volume present in the preforms and their mode of deformation during hot forging. But, their salient features remained more or less same. These curves can be divided into two distinct zones-the first zone involves higher rate of densification, but, low rise in the values of Poisson's ratio. Whereas, in the second zone high rise in the values of Poisson's ratio, but, least increase in densification. This zone is a confirmation of the fact that the flow of material and pores tend to become simultaneous.

III. 6 Mechanical Properties

Bars of square cross-section (~14 mm x ~14 mm) with a length of 100±05mm were machined to standard tensile specimens and the tension test has been conducted on a Hounsfield Tensometer. Tensile properties such as tensile and fracture strengths, per cent area reduction and per cent elongation were found out. These values are tabulated in Table–4. This table shows that iron with 2%TiC forming a composite has exhibited a nominal increase in tensile and fracture strengths. The value of % area reduction for this composite dropped from 39.41(for Fe-1%TiC) to 28.41 per cent whereas, elongation dropped marginally from 23.73 (for Fe-1%TiC) to 20.39 per cent. Fractographs shown in figures 8(a) and 8(b) indicate mostly ductile and partly brittle fractures. Fractographs show sufficiently high number of dimples, but, failure was facilitated due to particle de-lamination.

Table 4 Mechanical Properties of as Sintered and Forged Iron and Fe-1%TiC, and Fe-2%TiC Composites.

SYSTEM	T.S. (M Pa)	F.S. (M Pa)	% Elongation	% Area Reduction
Fe	410	720	28.92	47.33
Fe-1%TiC	490	767	23.73	39.41
Fe-2%TiC	580	770	20.39	28.41



(a) (b)

Figure 8 SEM Fractographs of Fe-TiC Composites, (a) Fe-1%TiC and (b) Fe-2%TiC.

IV. CONCLUSIONS

Based on the analysis of the experimental data, calculated parameters and various plots drawn, the following main conclusions were arrived at:

1. The Relationship between the fractional theoretical density (ρ_f/ρ_{th}) and the true height strains ($\ln(H_o/H_f) = \varepsilon h$) on hot forging was found to correspond to a third order polynomial of the type: $(\rho_f/\rho_{th}) = A_0 + A_1\varepsilon h + A_2\varepsilon h^2 + A_3Єh^3$; where, '$A_0$', '$A_1$', '$A_2$' and '$A_3$' are empirically determined constants which are found to depend upon the initial preform aspect ratio and their composition,
2. Poisson's ratio with respect to percent fractional theoretical density was found to be a function of initial preform aspect ratios and the compositions of the systems investigated. This presentation of data and calculated parameters for Poisson's ratio and the per cent fractional theoretical density tended to approach to a limiting value of 0.5, which is a theoretical value attainable in the near vicinity of theoretical density,
3. Tensile and fracture strength values for both the systems have been on the higher side, but, both systems showed high values of per cent elongation and per cent area reduction. These high values of elongation and per cent area reduction indicate that both the systems were equally tough.

REFERENCES

[1] A.K. Sinha, "Powder Metallurgy, Dhampat Rai Publications (P) Ltd., New Delhi, pp-1-3, 1997.
[2] Howard. A. Kuhn, "Manufacturing methods for composites – An Overview", Concise Encyclopedia of Composite Materials, Ed. By Antbony Kelly, pp 99-134, 1986.

[3] Donal S. Clark and Wilbur. R. Varney, "Physical Metallurgy for Engineers", Van Nostrand Co. Inc. pp 347-349, 1973.

[4] Ronald. L. Gibson, "Principles of Composite Materials Mechanics", McGraw Hill Inc. pp 1-11, 1994.

[5] William D. Callister. Jr., "Materials Science and Engineering – An Introduction", Composites, 3rd Edn. pp 513-540, 1994.

[6] D. Dutta, G. Mohan, B. Chatterjee and C.G. Krishnadas, " Indigenous Development and Manufacture of Aircraft Friction Materials by Powder Metallurgy," Transaction of Powder Metallurgy", PMAI, Vol.13, pp 12-20, 1986.

[7] A. Pathak, A.N. Tiwari and T.R. Ramamohan, "Sintered Cu-TiC Particulate Composites", Transactions of PMAI, Vol. II, pp 9-11, 1984.

[8] G. Suresh and G.S. Upadhyaya, "Sintering of High Speed Steel Bonded TiC Particulate Composites", Transactions of PMAI, Vol. II, pp 9-11, 1984.

[9] D.H. Bowen, Manufacturing Methods for Composites – An overview" Concise Encyclopedia of Composite Materials, Ed. By Anthony Kelly, pp 182-183, 1986.

[10] K.G. Satyanarayana, B.C. Pai, K. Sukumaran and S.G.K. Pillai, "Synthesis and Properties – A Hand Book of Ceramics and Composites", Vol. I, ED. By Nicholas, P. Chereemerinoff, pp 339-382, 19--.

[11] K.G. Satyanarayana, R.M. Pillai and B.C. Pai, "Aluminium cast matrix composites", A Handbook of ceramics and composites", Vol. I, Ed. By Nicholas P. Cheremerinoff, pp 555-599, 19--.

[12] Zhang Zhy, "A Literature Survey on Fabrication Methods of Cast Reinforced Metal Composites", Proceedings of the International Symposium on Advances in Cast Reinforced Metal Composites, Ed. By Fishman and A.K. Dingra, pp 93-100, 1999.

[13] Benea Lida, "Electro-deposition of Zirconia Particles in Copper Matrix", Materials and Manufacturing process, Vol.4, No.2, pp 231=242, March 1999.

[14] Gorsse. S., Chaminade. J.P., Le Peticorps.Y, "In Situ Preparation of Titanium Based Composites Reinforced by TiB Single Crystals by Using Powder Metallurgy Technique", Composites – Part – A: Applied Science and Manufacturing, Vol.29, No.9, pp 1229-1234, 1998.

[15] Rath. M. Kreuzbegfe, S. Hinrichsen.G., "Manufacture of Aramid Fiber Reinforced Nylon-12 by Dry Powder Impregnation", Composites Part A: Applied Science and Manufacturing, Vol.29, No.8, pp 933-938, 1998.

[16] Mosleh M. Suh N.P. Arinez. J., "Manufacture and properties of polyethylene Homo Composite", Composites Part A: Applied Science and Manufacturing, Vol.29, No.5-6, pp 611-617, 1998.

[17] Wang Juven, Hong Zao, Geyang Li, Pengxing Li, "Combined Process of Coating and Hybridizing for the Fabrication of Carbon Fibres Reinforced Aluminium Matrix Composites", Composites, Part A: Applied Science and Manufacturing, Vol.28, No.11, pp 943-948, 1997.

[18] F. Kickikalson, Thomas, B. Astrom, "Manufacturing and Applications of Structural Sandwitch Components", Composites Part A: Applied Science and Manufacturing, Vol.28, No.2, pp 97-111, 1997.

[19] A. Mclean, H. Soda, Q. Xia, et.al,: "SiC Particulate Reinforced Aluminium Matrix Composite Rods and Wires Produced by Continuous Casting Route", composites part A: Applied Science and Manufacturing, Vol.28, No.2, pp 153-162, 1997.

[20] R. Aldo Boccacuni, H.D. David Peare, A. Paul Trusty, "Pressureless sintering and characterization of Alumina Platelets Reinforced Barium-Magnesium Aluminosilicate Glass-Ceramic Composite", Composites Part A: Applied Science and Manufacturing, Vol.28, No.5, pp 505-570, 1997.

[21] Endang Zhang, P. Derch Thompson, "Carbon-Fibre Reinforcement on the Fibre Glass, Composites Part A; Applied Science and manufacturing, Vol.28, No.6, pp 581-586, 1997.

[22] Kon Bae Lee, Youn Su Kim and Houn Kwon, "Fabrication of Al-3Wt% Mg Matrix composities Reinforced with Al_2O_3 and SiC Particulates by Pressureless Infiltration Technique", Metallurgical and Materials Transacions A, Volume 294, pp 3087-3095, Dec.1998.

[23] R. H. Baskey, G. F. Davis and A.D.Sewope, "Fibre Reinforced Sintered Composites" * Vol.2, pp 332-338. 1965.

[24] G. Bocksteigel and O. Stevenson, "The Influence of Lubrication, Die Material and Tool Design Upon Die Near in the Compacting of Iron Powders", Modern developments in Powder Metallurgy, Ed. By Henery H. Hausner, Vol.4, pp 87-114, 1970.

[25] B. N. Singh, "Pressure less Densification of Powder Composites" , Powder Metallurgy, Vol.14, No.28, pp 277-280, 1971.

[26] N. D. Sopchak and W.Z. Misiolek, "Multilayer Compaction of Iron Powders", Advanced processing techniques in Powder Metallurgy and Particulate Materials, Compiled by Chaman Lall & Alberts J. Neupaver, Vol.6, pp 21-23, 1994.

[27] F. Thummbler and W. Thomma "Investigation of Sintering Process During Formation of Solid Solutions", Modern Developments in Powder Metallurgy, Vol.3, Ed by H. H. Hausner, pp 361-375, 1965.

[28] C. J. Leadbeater, I. Northcott and F. Hargarveas, "Some properties of Engineering Iron Powders", Iron powder Metallurgy, Vol.3, Ed. By Henery H. Hansner, K.H. Roll and P.K. Johnson, pp 117-118, 1968.

[29] B. Avitzur and P. Blum, "Forging and Extrusion of Powder Metallurgy Preforms", Modern Developments in Powder Metallurgy, Ed. By Henery H. Hausner and Walter E. Smith, Vol.7, pp 90-93, 1973.

[30] Richard W. Hertzberg, "Deformation and Fracture Mechanics of Engineering Materials", 4^{th} Edn. John wiley and Sons, Inc., New York, pp 380-386, 1996.

[31] Gerhard Bocksteigel, "Relations Between Pore Structure and Densification in Compacting Iron Powders", Iron Powder Metallurgy, Ed. By Henery H. Hausner, K H. Roll and P.K. Johnsons, Vol.3, pp 54-57, 1968.

[32] H. F. Fischmeister, B. Aren, K. E. Easterling, "Deformation and Densification of Porous Preforms in Hot Forging", Powder Metallurgy, Vol.14, pp 144-153, 1971.

[33] G.T. Brown and P.K. Jones, "Experimental and Practical Aspects of the Powder Forging Process", Modern Developments in Powder Metallurgy, Ed. By Henery H. Hausner, Vol.4, pp 368-383, 1971.

[34] H. N. Tewari and R. Sharan, "Forging of Iron and Steel Powder Preforms – A" critical Review, PMAI. Newsletter, A Quarterly Publication of the P/M Association of India, Vol.12, No, pp 15-18, March 1986.

[35] www.micronmetals.com/titanium Carbide.Html from AEE Home page.

[36] K. H. Roll, "Challenges and Opportunities for Powder Metallurgy in Structural Applications", Powder Metallurgy, Vol.25, pp 159-165, 1982.

[37] G.S. Upadhyaya, "Extending Role of Powder Metallurgy in Advanced Ceramics", A Quarterly Publication of Powder Metallurgy Association of India, Vol.13, No.4, pp 26-29, Sept.1987.

[38] Kunal Ghosh, Tom Troczynski and Asoke C. Chaklader, "Processing of Composite Al/Sic Powders for Plasma Spraying", International Journal of Powder Metallurgy, Vol.35, No.2, pp 27-33, March 1999.

[39] R. K. Galgali, H. S. Ray and A.K. Chakrabarti,"Preparation of TiC Reinforced Steel Composites and Their Characterization", Materials Science and Technology, Vol.15, pp 431-442, April 1999.

[40] Mujin Yang and Randall M. German, "Defect Formation and Densification Analysis of Particulate Materials, Ed. By Chaman Lall and Albert J. Neupaver pp 95-108, 1994Cemented Carbides Made by Powder Metallurgy Injection Molding", Advances in Powder Metallurgy.