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EXPERIMENTAL STUDY ON DEFORMATION AND DENSIFICATION PROPERTIES OF SINTERED ATOMET 4601+TIC ALLOY STEELS UNDER COLD UPSETTING

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ABSTRACT

The present investigation is focussed on to develop and study the densification and deformation of cold forged pre-alloyed ATOMET 4601 and admixed with 2% TiC high strength alloy steels. Elemental TiC powder was homogeneously mixed with ATOMET prealloyed powder through Powder Metallurgy (P/M) route. The physical properties of P/M alloy steel powders were measured as per the ASTM Standards. The cylindrical sintered preforms of size Ø25x12 mm were used for the present work. In order to study the plastic deformation and densification characteristics of the alloy steels preforms, the specimens were subjected to cold upset with an incremental load. The axial load was increased upto the appearance of fine cracks on the lateral surface of the deformed alloy steel preforms. Physical measurements have been taken on deformed and undeformed specimens to calculate stress and strain values. The density of specimens was evaluated by the Archimedes' principle for the as sintered and the specimen after each deformation. The influencing parameters such as true axial stress, true height strain, true lateral strain, density and hardness were correlated each other for the deformation and densification studies of the alloy steels. Microstructures of alloy steels taken by optical microscope were also corroborated with deformation properties. It is found from the plots that addition of TiC to prealloyed powder deteriorates the plastic deformation and densification properties of ATOMET 4601 alloy steel. The titanium carbides embedded between the ferrite gains drastically affect the plastic flow of TiC added alloy steel.

Keywords- ATOMET 4601+2%TiC, Densification, Microstructure, Plastic deformation, True Axial stress.

I. INTRODUCTION

Forging is accepted as economical and an effective method of improving the density as well as the mechanical properties through promotion of homogeneous structure. German (1998), Kuhn and Downey (1971) and Lee et al., (2002) have explained that Powder Preform Forging (PPF) has further advantages viz. optimum utilization of material, single blow finishing operation, and isotropic properties. The densification and deformation of alloy preforms also depends on the alloying element, alloy types and micro-structural phases formed during sintering and post sintering operations. The density level obtained in sintering is always much less than the theoretical value because of the difficulties involved in elimination of small rounded pores (Channankaiah, et al., 2012). Occurrence of such micro pores always renders the specimen weak because these pores act as sites of origination of fracture during service. In addition to enhance the density of sintered products, post sintering operations on the preforms can be done. Mamalis, et al., (1999) have explained that the factors influencing the geometric change of the pore are the pattern and the level of the plastic deformation processes such as cold forging, hot forging, repressing of the sintered polished preforms, which resulted in improved density will result in improved density. The sintered density, pore distribution and size, aspect ratio of the preforms etc., are the main parameters for the P/M preform characteristics during post sintering operations. Mechanical behaviour of sintered P/M alloys (Shanmugasundaram, et al., (2009), Kandavel et al., 2010) have reported that the initial density of preforms is significantly influenced by the inherent porosity, which can be removed to a great extend when the sintered alloys are subjected to cold or hot forging subsequent to sintering. The material strength is enhanced by the way of reaching maximum density of sintered performs and dependent on the way on which it can achieve better mechanical properties (Vamsikrishna, et al., 2004). The quality of the product obtained through PPF is very much influenced by the various process parameters such as forging temperature, initial preform density and alloying elements (Chandramouli, et al., 2012). Pandey (1991) illustrated that the demand for cheaper but high strength structural alloys has driven the P/M industry to seek newer compositions with wider applications of Fe-C alloys. The economic factor plays a vital role, so that 80% of structural and automotive parts are produced through powder metallurgy technique. German, (1998), Kuhn and Downey (1971) explained that the powder metallurgy process enables the products to be made that are capable of absorbing upto 35% of selected fluids.

II. EXPERIMENTAL DETAILS

ATOMET 4601 is a highly compressible, water-atomized alloy steel powder containing 1.8% nickel and 0.55% molybdenum procured from Rio Tinto - QUEBEC METAL POWDERS, Canada being used as an base powder for specimen preparation. The physical characteristics such as flowability, tap density and apparent density of the ATOMET 4601 and ATOMET 4601+2%TiC alloy steel powders have been measured using ASTM Standards (B213-13, B527-15, B212-13) and their results are provided in Table 1.

Table 1: Physical properties of pre-alloyed and elemental powders

No.	**Composition**	Theoretical density (g/cc)	Apparent density **(g/cc)**	Tap density (g/cc)	Flowability (s/g)
1	ATOMET 4601	6.95	2.35	2.56	0.62
2	ATOMET 4601+ 2% TiC	6.89	2.50	2.66	0.72

The prealloyed and blended powders were compacted incylindrical performs of aspect ratio 0.5 (h/d) using Universal Testing Machine (UTM) of capacity 1000kN with suitable die-punch setup. Graphite powder mixed with lube oil is used as a lubricant during compaction in order to avoid die-wall friction. After preparing cylindrical performs, ceramic coating is done in order to avoid oxide formation on green compact and made to dry for 24 hrs. Upon the specimen being dried, it is subjected to sintering using 2.5kW capacity electrical muffle furnace at a temperature 1100±10°C for a period of 30 minutes soaking. The sintered specimens were cleaned and machined to have uniform size. The hardness of the specimens in the as sintered condition has been taken using Rock Well hardness tester. The same UTM was used with flat dies to conduct deformation and densification tests on the specimens of P/M alloy steels. The gradual incremental load was applied on the specimen and the corresponding physical dimensional changes were measured using three decimal Mitutoyo digital vernier. The application of axial load was continued till the appearance of fine cracks on the lateral surface of the deformed preforms of the alloy steel. The densities of as sintered and deformed specimens were measured by the Archimedes' principle. The hardness after each incremental load application was also measured. The parameters such as true axial stress, true height strain, true lateral strain and %theoretical density of P/M alloy steels were calculated using the physical measurements taken from the deformed and undeformed specimens. The plastic deformation and densification characteristics of the alloy steels have been discussed by correlating various influencing parameters such as stress, strain, density and hardness. The surface morphology of the maximum deformed preforms of the alloy steels have also been corroborated with the deformation and densification properties of the alloy steels.

III. RESULTS AND DISSCUSION

A. *True Axial Stress Vs True Axial Strain*

Fig.1 shows the axial plastic deformation of alloy steels at various axial applied stress values. It is observed that the axial plastic deformation trend is similar to both alloy steels. The rate of axial working stress and strain of the deforming material depends on the initial porosity of the preform as well as the pore flattening effect during the deformation processes. The effect of pore shrinkage and deformation results in further hardening of the material (geometrical hardening), which further influences the material flow and densification. It is found that a ATOMET 4601 preform gives a marginal increase in axial stress value compared to that of ATOMET 4601+ 2% TiC because of uniform densification of preforms. Addition of 2% TIC to the ATOMET 4601 causes the perform to less stress and strain harden when compared to the ATOMET 4601.

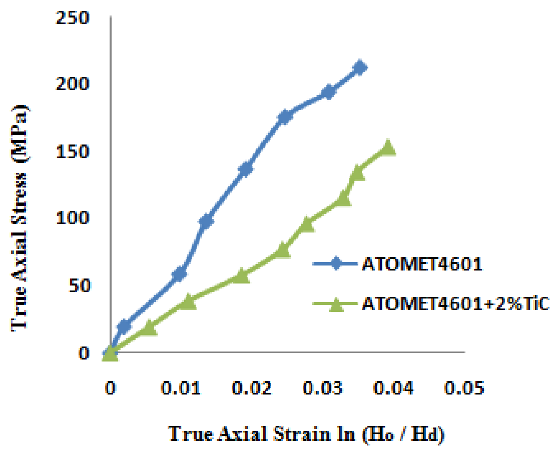

Fig.1. Plot of true axial stress versus true axial strain

B. *True Axial Stress Vs True Lateral Strain*

Fig. 2 shows the plot of true axial stress versus the lateral strain of two alloy steels. The trend observed in the figure is similar to the axial deformation plot. The rate at which the alloy steels deform in the lateral direction is found to be same. The hierarchy exhibited by the ATOMET 4601 + 2% TIC alloy in lateral strain variation during cold upsetting has a better strain hardening effect involving less stress compared to ATOMET 4601.

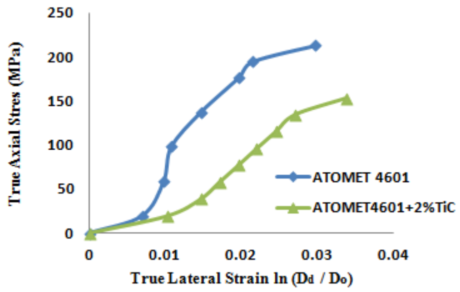

Fig.2. Plot of true axial stress versus true lateral strain

C. True Axial Stress Vs %theoretical Density

Fig. 3 shows the densification characteristics of the alloy steels with respect to axial applied stress. The initial density of preforms was set at 78±2% theoretical density of the concerned alloy steels in order to prevent the influence of initial density on the densification property of the alloy steels. It is observed from the plot that the ATOMET 4601 exhibits higher densification compared to the alloy steel of TiC addition. TiC is a known hard alloying element, which attributes to deteriorate the densification property of the alloy steel. The addition of TiC invariably enhances the hardness of the material.

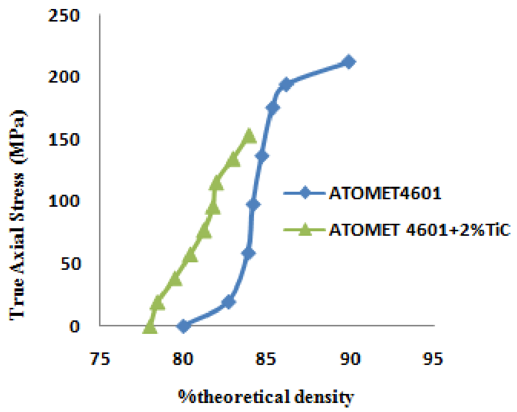

Fig.3. Plot of true axial stress versus % theoretical density

D. %theoretical Density Vs True Axial Strain

Fig. 4 shows the densification and axial plastic flow properties of the alloy steels. Both the alloy steels exhibit similar kind of trend in the densification and deformation properties. Though the alloy steels exhibit same level of axial flow, the densification level is different. This is due to the addition of hard alloying element TiC with the base material.

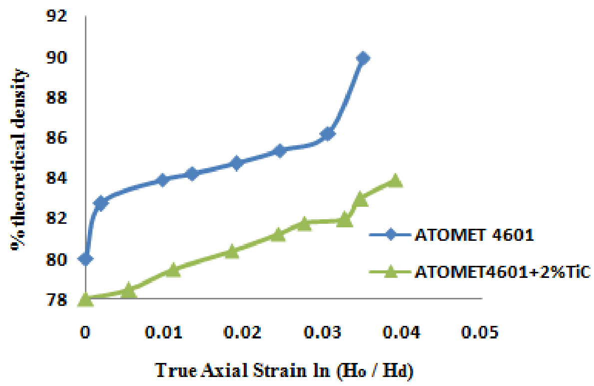

Fig.4. Plot of % theoretical density versus true axial strain

E. Hardness Vs %theoretical Density

Fig. 5 shows the variation of hardness with respect to density attained by the alloy steels at each incremental applied load. One of the unique properties of the P/M material is enhancement of density and hardness during plastic deformation of material, which in turn improves the mechanical properties of the P/M material. The plot shows the improvement of both density and hardness with respect to incremental applied load. It is clearly understood from the plot that addition of TiC to ATOMET 4601 prealloyed steel material significantly enhances the hardness during plastic deformation of alloy steel. This could be due to the formation of carbides during sintering by the concerned alloy element.

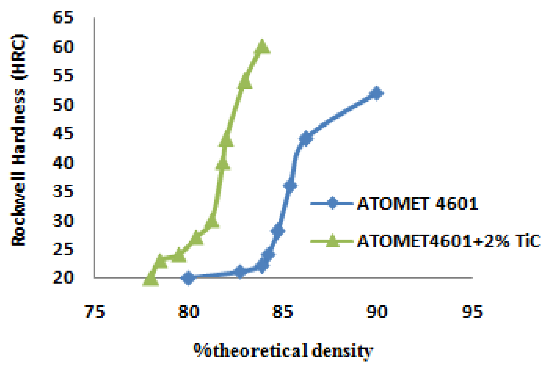

Fig.5. Plot of Rockwell hardness versus %theoretical density

F. Microstructure

Figure 6a and b show the surface morphology of as sintered alloy steels. The basic microstructures observed from the images are ferritic. The large size ferrites grains along with carbide phases are seen in the images. Uniformly spread micro pores are also observed in the microstructure. In the case of TiC added alloy steel, Ti carbides embedded in between the large size ferrite grains are observed, which is the phase affect the densification property of the alloy steel during plastic deformation.

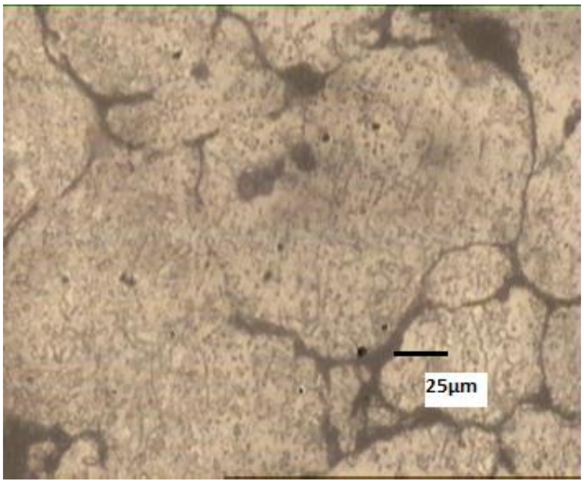

Fig. 6a: Microstructure of as sintered ATOMET4601

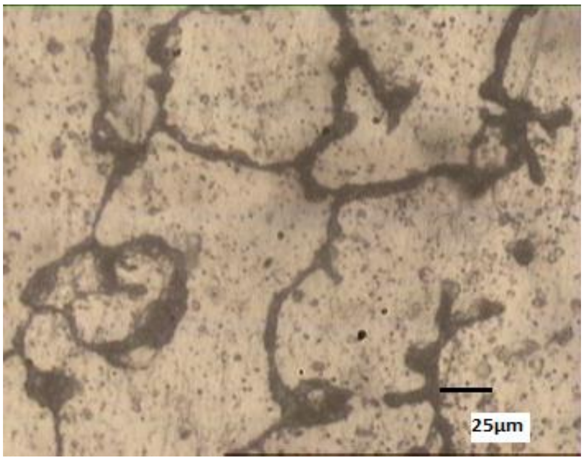

Fig. 6b: Microstructure of as sintered ATOMET4601 +2%TiC

Figure 6c depicts the microstructure of the ATOM ET 4601 alloy steel. The enlarged ferrite grains are visible with clear grain boundary and randomly distributed pores are also observed in the figure. As the material contains appreciable amount of Mn and Mo, the corresponding carbides are also seen in between the ferrite grains, which in turn improves the mechanical property of the material.

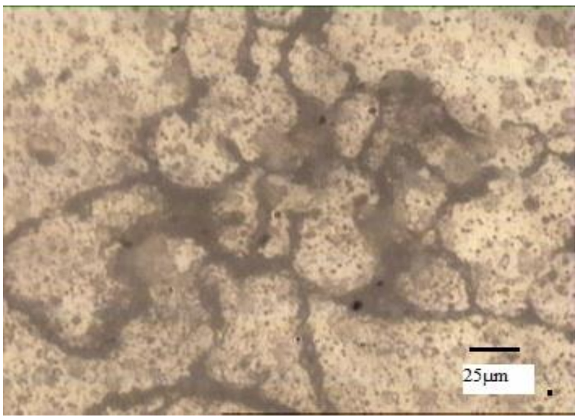

Fig. 6c: Microstructure of densified ATOMET4601

The microstructure of TiC added base material is shown in Figure 6d. The carbide phases of Ti randomly appeared in the figure. The formation of hard carbide phases determines the deformation and densification properties of the concerned alloy steel. These carbide phases enhance the hardness to the appreciable level in the alloy steel.

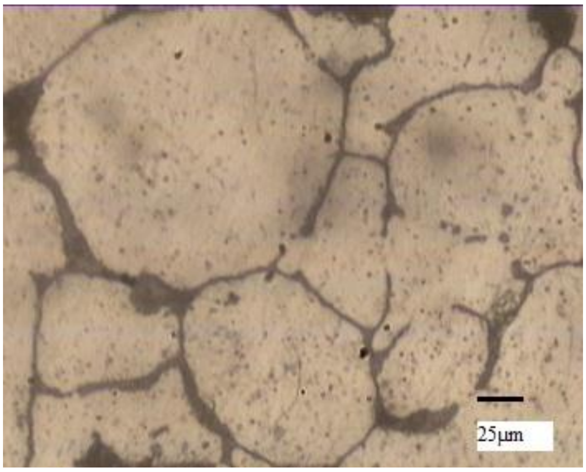

Fig. 6d: Microstructure of ATOMET4601 +2%TiC

CONCLUSIONS

TiC addition to ATOMET 4601 is found to influence not to that extend on deformation property rather than densification property of the base material. However, TiC addition leads to greater hardness enhancement in the alloy steel when compared to ATOMET 4601. The formation of hard carbide phases is observed to responsible for the higher hardness in the alloy steel.

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