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Influence of temperature on the workability and hardness of sintered Al-4%B_4C in upsetting test

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Abstract

The present investigation has been made on the influence of temperature on the workability behavior, stresses and hardness of sintered Al-4%B_4C at a strain rate of $0.1 s^{-1}$ during upsetting. Al-4% B_4C preforms were prepared with 90% of initial preform density and sintered at 550±10ºC about 60 min. These sintered preforms were compressed in a hydraulic press at a strain rate of $0.1\ s^{-1}$ until the initiation of the cracks appears on the free surface. The various stresses (σ_z, σ_θ, σ_m, σ_{eff}), formability stress index (β) and stress ratio parameters (σ_z/σ_{eff}, σ_m/σ_{eff}, $\sigma_\theta/\sigma_{eff}$) were calculated and correlated with the true axial strain (ε_z). Also the effect of different deformation temperatures on the hardness of Al-4%B_4C preforms was studied in detail.

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Keywords: Boron carbide; Upsetting; Formability stress index (β); Hardness; Temperature.

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1. Introduction

Aluminium matrix composites (AMCs) are found to be potential material in the industrial world due to their better mechanical and physical properties, and it is widely used in automobile, aerospace, marine, military industries and etc [1, 2]. In AMC, aluminium matrix properties can be enhanced by addition of metals or hard ceramic particles like, SiC, Al_2O_3 and B_4C etc. B_4C is one of the alternative materials to SiC and Al_2O_3 as reinforcement to enhance the

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properties of AMCs [1] due to its excellent properties such, low density (2.52 g/cc), high hardness (30 GPa), chemical stability [3, 4]. This AMC finds applications in bullet-proof vests in defense and fuel storage tank in the nuclear industry [1, 5, and 6]. Al-B_4C composite system is unitary the fascinating material systems, and it has been fabricated through Powder Metallurgy (P/M) route. P/M technique is one of the effective routes to manufacture the aluminium metal matrix because it is cost effective, and a net shape manufacturing process. The major disadvantage of the P/M route produces the component with porosity after sintering. Several secondary processes are available to eliminate the porosity in the P/M component. Among which, upsetting forging process is desirable because it has various advantages like cost and material effective, high production rate and properties enhancement [7, 8]. Few works have been done based on the Al composite with reinforcement of hard ceramic particles. K. Kalaiselvan et al. [2] investigated that the AA6061-B_4C fabricated through the stir casting process and reported that the mechanical properties are improved with the addition B_4C particles in the aluminium composite. E. Mohammad Sharif et al. [1] studied the mechanical and tribological properties of Al-B_4C composites, and revealed that the properties was enhanced with increasing B_4C content in the Al composite. Till now several authors studied about Al-B_4C composites, which include fabrication, microstructure, tribological characteristic and mechanical properties. There is limited research work have been done on formability and mechanical properties of sintered composite material for various temperatures. Hence, there is need to understood mention properties because they are playing important role in many structural applications. The present investigation has been done on the sintered Al-4%B_4C preforms to study the workability behavior and mechanical properties during upsetting process under triaxial stress state condition for various temperatures.

Nomenclature

D_o	initial diameter of the preform (mm)
D_B	bulged diameter of the preforms after deformation (mm)
D_{CT}	contact top diameter of the preforms after deformation (mm)
D_{CB}	contact top diameter of the preforms after deformation (mm)
H_o	initial height of preform (mm)
H_f	height of the preform after deformation (mm)
ρ_o	initial preform density of the cylinder (g/cc)
ρ_f	density of the cylinder after the deformation (g/cc)
ε_z	true axial strain
ε_θ	true hoop strain
σ_z	true axial stress (MPa)
σ_θ	true hoop stress (MPa)
σ_m	true hydrostatic stress (MPa)
σ_{eff}	true effective stress (MPa)
R	relative density
β_σ	formability stress index

2. Experimental procedures

2.1. Materials

Sintered Al-4%B_4C preforms were prepared from aluminium and boron carbide powders of -325 mesh size. The purity level of the atomized aluminium powder is 99% with a maximum of 0.53% insoluble impurities. Boron carbide purity is 99.7% and the rests are insoluble impurities. The SEM morphology of as received aluminium and boron carbide powder as shown in Fig.1 and it is observed that the both are in flaky shape.

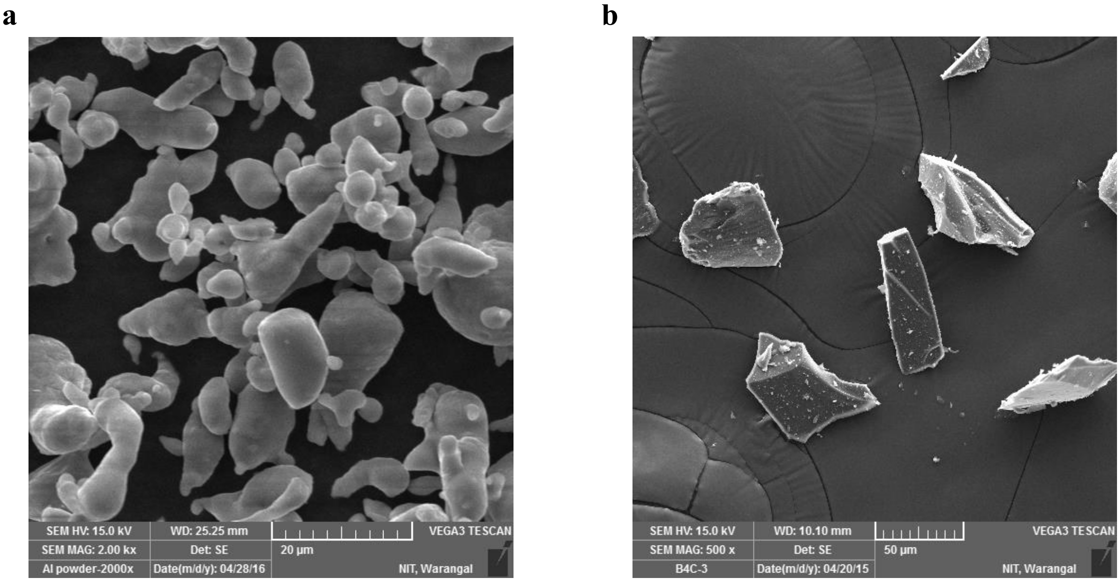

Fig. 1. SEM image of (a) Aluminium and (b) Boron carbide powder

2.2. Blending, compaction and sintering

Al and B_4C powder were blended in pot mill with the help of the porcelain ball at a constant speed about 1 hour and yielding the composition of Al-4%B_4C. The morphology of the Al-4%B_4C was analyzed with the help of SEM as shown in fig. 2. , and it was found to be homogeneous. The powder mixture of Al-4%B_4C were compacted into a cylindrical shape of diameter and height of 15 mm by using hydraulic press (50 ton) at a pressure of 275 ± 5 MPa in order to obtain 90% initial preform density (IPD). Zinc stearate was used as a lubricant during the compaction process and applied the inner surface of the die and outer surface of the punch to avoid sticking of powder on these surfaces and for easy ejection. The green compacts were sintered in an electrical muffle furnace at a 550 ± 10ºC about 60 min left in the furnace itself to cool at room temperature.

2.3. Cold and hot upsetting

After sintering, the initial dimensions of preforms such as diameter (D_o), height (H_o) and density (ρ_o) were measured. The compression test was carried out between two flats dies in a hydraulic press at a strain rate 0.1 s^{-1} during cold and hot upsetting. The hot deformation process is conducted inside the electrical resistance split muffle furnace with various temperatures 300-500ºC. The incremental compressive load was applied to specimen until the initiation of the cracks appears on the free surface during the triaxial stress state condition. After each step of deformation the dimensional changes in the specimen, such as height (H_f), top contact diameter (D_{CT}), bottom contact diameter (D_{CB}), and bulge diameter (D_B) was measured with the aid of the digital vernier caliper. The initial and final density (ρ_f) of the preforms was measured by using Archimedes principles with an accuracy ± 0.01 and recorded. From the above measured data the stresses such as, true axial stress (σ_z), true hoop stress (σ_θ), true hydrostatic stress (σ_m), true effective stress (σ_{eff}) formability stress index (β_σ) and axial strain (ε_z) were calculated. The upsetting parameters were determined by the following mathematical expressions under triaxial stress state condition [9, 10].

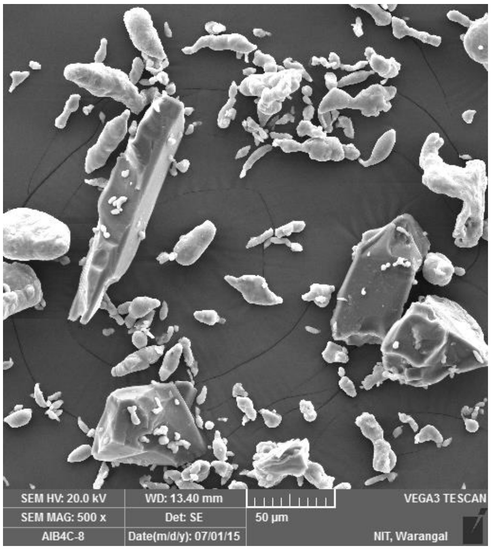

Fig. 2. Photograph of Al-4%B_4C composite

The true axial strain (ε_z), axial stress (σ_z) component of powder metallurgy composite preforms can be calculated from the following equations.

$$\varepsilon_z = \ln\left(\frac{H_f}{H_o}\right) \tag{1}$$

$$\sigma_z = \frac{load}{contact\ surface\ area} \tag{2}$$

The hoop strain (ε_θ) which includes the forged bulged diameters (D_B) and forged contact diameters of the preforms can be expressed as follows:

$$\varepsilon_\theta = \ln\left[\frac{2D_B^2 + D_C^2}{3D_o^2}\right] \tag{3}$$

Where D_C is average surface contact diameters of the preforms after the deformation.

The true hoop stress (σ_θ) can calculate from the Eq (5) as

$$\sigma_\theta/\sigma_z = \left[\frac{2\alpha + R^2}{2 - R^2 + 2R^2\alpha}\right] \quad (\text{Where}\ \alpha = \frac{d\varepsilon_\theta}{d\varepsilon_z}) \tag{4}$$

When α is Poisson’s ratio, R is relative density.

The true hydrostatic stress is calculated by

$$\sigma_m = \frac{2\,\sigma_\theta + \sigma_z}{3} \tag{5}$$

The true effective stress can be determined from the following relation as

$$\sigma_{eff} = \left[\frac{\sigma_z^2 + 2\sigma_\theta^2 - R^2(\sigma_\theta^2 + 2\sigma_z\sigma_\theta)}{2R^2 - 1}\right]^{0.5} \tag{6}$$

The formability stress index ‘β_σ’ defined as follows:

$$\beta_\sigma = \left(\frac{3\sigma_m}{\sigma_{eff}}\right) \qquad (7)$$

The micro hardness test was conducted on Al-4%B_4C composite preforms using Vickers hardness tester to study the effect of temperatures. Vickers hardness was measured at room temperature on polished preforms using an ball indenter with 2.5 mm diameter with load of 200 gf and a dwell time of 15 sec. for deformed preforms (cold and hot). For each of the preforms, five readings were measured for randomly chosen region and considered the average of those values.

3. Results and discussions

3.1. Stress analysis

The true axial stress (σ_z) – true axial strain (ε_z) curves of sintered Al-4%B_4C preforms with initial relative density of 90% at a strain rate 0.1 s^{-1} during upsetting with various temperature are depicted in Fig. 3a.

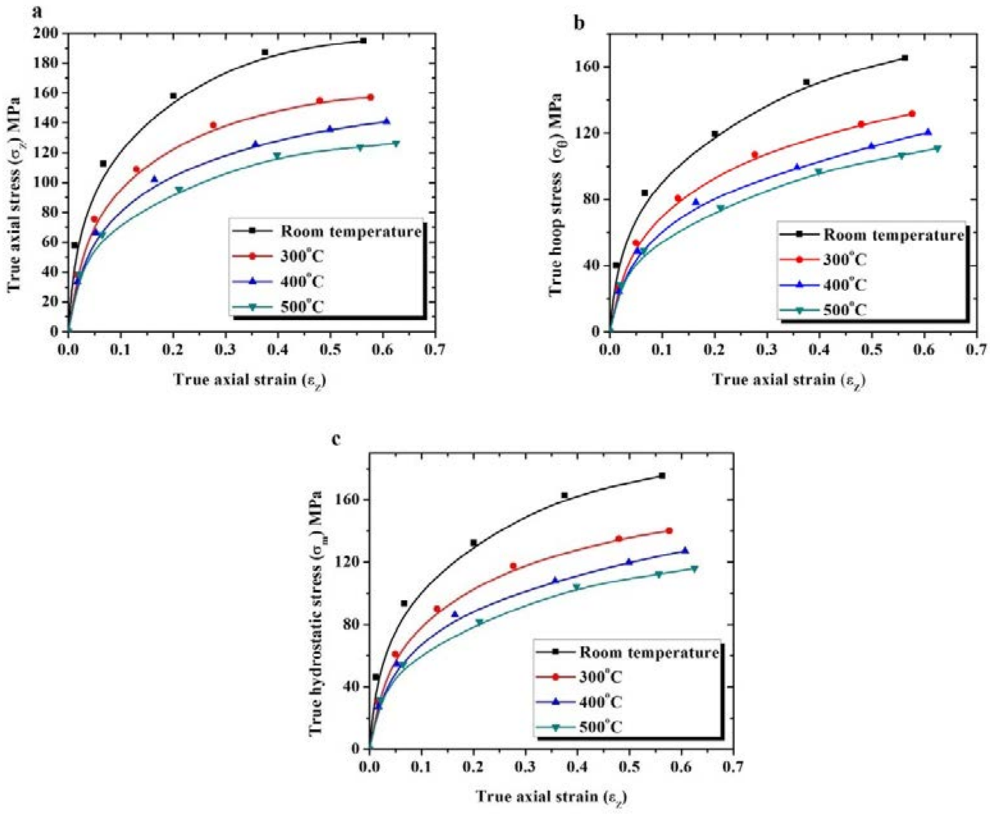

Fig. 3. (a) True axial stress vs True axial strain (b) True hoop stress vs True axial strain (c) True hydrostatic stress vs True axial strain

It is noticed that the true axial stress is increasing with respect to axial strain during upsetting with various temperature. Initially the true axial stress is increasing rapidly up to 0.2 true axial strains then increase slowly for remaining true axial strain because of very limited flow softening. It can be found that the influence of temperature on true stress – true strain curve is quite significant for all experimental conditions. As the deformation temperature increases the flow stress is decreasing because at a higher temperature the motion rate of dislocation increased at the same time fewer deformation load is required to close the pores. The decrease in true axial stress because of increase in deformation temperature and it contributes to the decrease in porosity.

The same kind of behavior observed for other stresses such as, true hoop stress (σ_θ) and true hydrostatic stress (σ_m) with true axial strain (ε_z) as demonstrated in Fig. 3(a & b). As increasing the deformation temperature the true hoop stress and true hydrostatic stress are decreased with respect to true axial strain under triaxial stress state condition. Moreover, higher true strain (better deformation) was observed in the higher deformation temperature (500ºC) with lower applied stress. However hot upsetting preforms shows higher axial strain (ε_z) with lower applied stress because pores are closing with less load during plastic deformation.

3.2. Workability behavior of Al-4%B$_4$C composite performs

Fig.4a. the graph has been plotted between the formability stress index (β_σ) and true axial strain for the Al-4%B$_4$C P/M preforms during upsetting process under triaxial stress state condition for various temperatures.

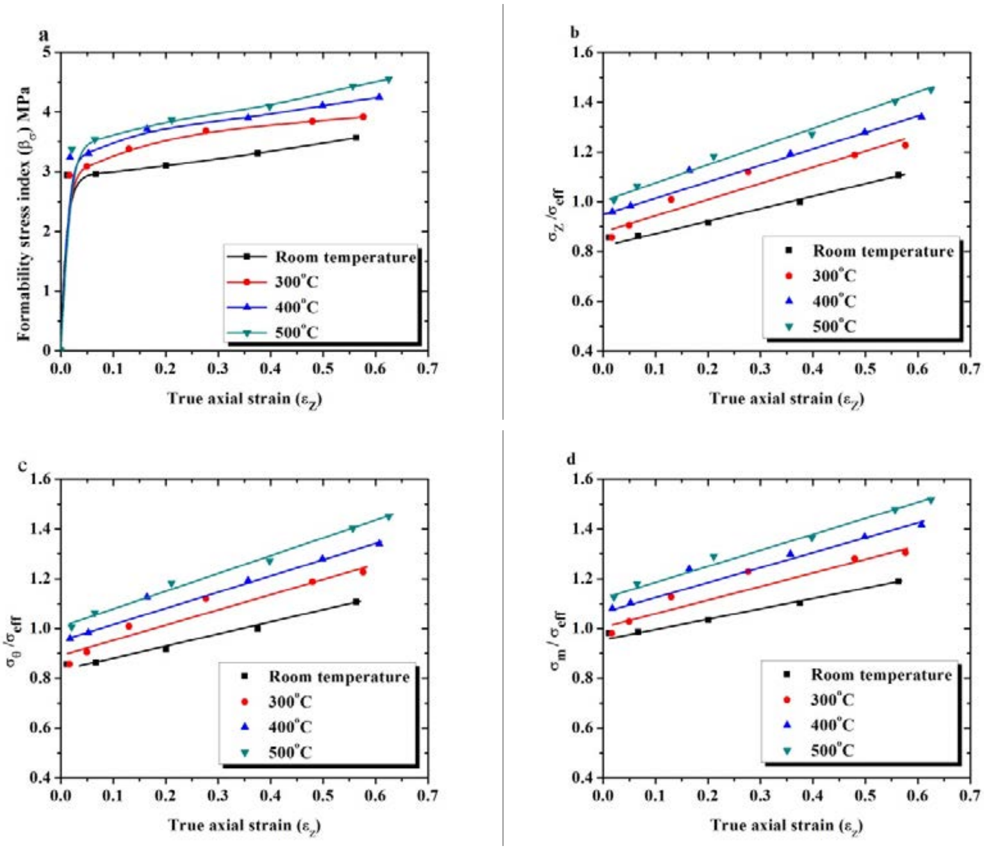

Fig. 4. (a) Formability stress index vs True axial strain (ε_z) (b) Stress ratio parameters (σ_z / σ_{eff}) vs True axial strain (ε_z) (c) Stress ratio parameters ($\sigma_\theta / \sigma_{eff}$) vs True axial strain ($\varepsilon_z$) (d) Stress ratio parameters (σ_m / σ_{eff}) vs True axial strain (ε_z)

It is observed that the formability stress index increased with respect to true axial strain for upsetting. The reason increase in formability stress index with applied stress is due to increasing in the relative density and hydrostatic stress

(σ_m) of sintered preforms. While applying axial load the solid particle is migrated to the void places is nothing but pores closing phenomenon and contributed to the increase in the relative density. Further, it is observed that, the deformation temperature greatly influencing the formability stress index during hot upsetting. With increase in deformation temperature the flowability of the material increased and low deformation load is required to close pores. The formability stress index increased with increasing deformation temperature and it was found higher formability at 500°C deformation temperature with maximum true axial strain at low deformation load.

Fig. 4(b-d) shows the graph, stress ratio parameters (σ_z/σ_{eff}, $\sigma_\theta/\sigma_{eff}$, σ_m/σ_{eff}) against true axial strain (ε_z) for the sintered Al-4%B_4C preforms during both cold and hot upsetting process. It is noticed that the stress ratio parameters (σ_z) increases with increasing true axial strain (ε_z) for all experimental conditions. The increases in the deformation temperature also increase in stress ratio parameters, due to increase the relative density by closing the pores. The highest stress ratio parameter observed at 500°C deformation temperature because of porosity is minimizing. The same kind of behavior is observed for remaining stress ratio parameters ($\sigma_\theta/\sigma_{eff}$, σ_m/σ_{eff}) with respect to true axial strain (ε_z).

3.3. Hardness test for Al-4%B_4C preforms

The effect of forming temperatures on hardness properties of deformed Al-4%B_4C composite preforms as shown in Fig. 5. The hardness of the samples was measured after the fracture. It has been observed that hardness values increase with increasing deformation temperature up to 400°C where as at 500°C deformation temperature the hardness value is decreased. With increasing deformation temperature, the strength of the preforms increases due to increasing relative density by closing pores in the preforms. The porosity of the Al-4%B_4C preforms were measured after the deformation are 7.8%, 7%, 6.2% and 5.6% for room temperature, 300°C, 400°C and 500°C, respectively. The hardness values of the fracture preforms at various temperature as shown in Table 1.

During deformation process, in Al-B_4C composite the carbide precipitation are continuously coarsened when the deformation temperature increased and it was probably peak at 500°C. This result indicated that the strength of the 500°C preforms decreased, which shows less hardness.

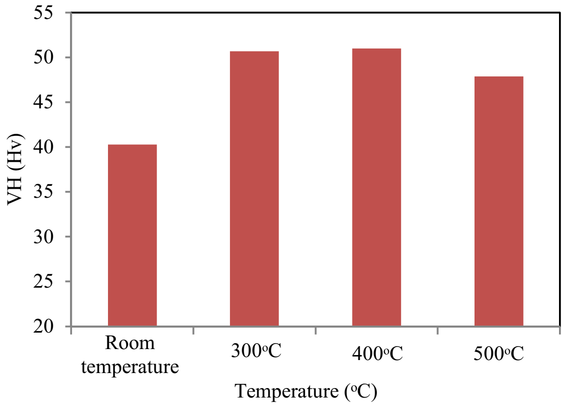

Fig. 5. The effect temperatures on hardness test for Al-4%B_4C composite.

Table 1. Hardness values of deformed preforms at various temperature.

Temperatures (°C)	Vickers Hardness values (Hv) Deformed preforms
Room temperature	40.26
300	50.68
400	51.00
500	47.8

4. Conclusions

The effect of temperature on Workability and hardness has been studied on sintered Al-4%B_4C composites by upsetting test for various temperatures under triaxial stress state condition. The following conclusion could be drawn such as.

1. The forming temperature is more influencing on the true stress – true strain curve and formability parameters and it is quite significant for investigated experimental conditions.
2. Higher true strain (better deformation) was observed in the higher deformation temperature (500°C) with lower applied stress.
3. The formability of Al-4%B_4C increased with increasing forming temperature and it was found higher formability at 500°C with maximum true axial strain and low deformation load.
4. The hardness values were increased with increasing deformation temperature up to 400°C during upsetting process.

References

[1] E. Mohammad Sharifi, F. Karimzadeh, M.H. Enayati, Fabrication and evaluation of mechanical and tribological properties of boron carbide reinforced aluminum matrix nanocomposites, Mater. Des. 32 (2011) 3263–3271.

[2] K. Kalaiselvan, N. Murugan, Siva Parameswaran, Production and characterization of AA6061–B_4C stir cast composite, Mater. Des. 32 (2011) 4004–4009.

[3] Fatih Toptan, Ayfer Kilicarslan, Ahmet Karaaslan, Mustafa Cigdem, Isil Kerti, Processing and microstructural characterisation of AA 1070 and AA 6063matrix B_4Cp reinforced composites, Mater. Des. 31 (2010) S87–S91.

[4] A. Baradeswaran , S.C. Vettivel , A. Elaya Perumal , N. Selvakumar , R. Franklin Issac, Experimental investigation on mechanical behaviour, modeling and optimization of wear parameters of B4C and graphite reinforced aluminium hybrid composites, Mater. Des. 63 (2014) 620–632.

[5] Mohanty R.M. Balasubramanian K, Boron rich boron carbide, An emerging high performance material. Key. Eng. Mater. 395 (395) 125–142.

[6] J. Abenojar, F. Velasco, M.A. Martinez, Optimization of processing parameters for the Al + 10% B_4Csystem obtained by mechanical alloying, J. Mater. Process. Technol. 184 (2007) 441–446.

[7] R. Chandramouli, T.K. Kandavel, D.Shanmugasundaram, and T. Ashok Kumar, Deformation, densification, and corrosion studies of sintered powder metallurgy plain carbon steel preforms, Mater. Des.28 (2007) 2260–2264.

[8] Manickam Ravichandrana, Abdullah Naveen Saita, Veeramani Anandakrishnan, Workability studies on Al+2.5%TiO_2+Gr powder metallurgy composites during cold upsetting, Mater. Res. 17(6) (2014) 1489-1496.

[9] Abdel-Rahman M, and El-Sheikh M. N, Workability in forging of powder metallurgy compacts. J. Mater. Sci. Process. Technol. 54 (1995) 97-102.

[10] R. Narayanasamy, V. Anandakrishnan, K.S. Pandey, Effect of carbon content on workability of powder metallurgy steels, Mater Sci. Eng. A 494 (2008) 337–342.