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Research Paper

Hot workability and densification behavior of sintered powder metallurgy Al-B_4C preforms during upsetting

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ABSTRACT

The workability and the densification behavior of a porous Al–B_4C preforms have been carried out in the present investigation. Hot upsetting tests have been carried out on Al–B_4C powder metallurgy (P/M) preforms having an initial preform density of 0.9 and having different B_4C compositions of 2%, 4% and 6%. The samples were compressed between two flat dies in a hydraulic press of 50 ton capacity under varying deformation temperatures such as 200 °C, 300 °C, 400 °C and 500 °C under the tri–axial stress state condition. The workability and densification behavior of Al–B_4C preforms were analyzed till the initiation of cracks on the outer surface of the preform. The experimental results were analyzed for the various deformation parameters such as axial strain, relative density, formability stress index and different stress ratio parameter under the tri–axial stress state condition. The formability and densification behavior were discussed with the axial strain (ε_z) during the hot upsetting process. The relationships between the various stress ratio parameters (σ_q/σ_{eff}, σ_m/σ_{eff}) and formability stress index (β_σ) as a function of the relative density under the tri–axial stress state condition were established.

1. Introduction

Metal matrix composites (MMCs) are attractive materials for aerospace industries, automobile industries, nuclear industries, etc. due to their mechanical properties such as high strength to low weight ratio, high wear resistance, high corrosion resistance, high stiffness, etc. [1]. Generally, Aluminium metal is used as a matrix material due to its light weight, high elastic modulus, high strength, and good wear resistance. Ceramics are used as reinforcement material because it provides sufficient strength and stiffness to the matrix material [2]. Until now, the ceramics such as SiC, Al_2O_3, TiC, TiB_2, TiO_2, WC, Fe_3C and Mo_2C have been used in the aluminium matrix material as reinforcement material [3–7]. However, Boron carbide (B_4C) is a low dense but hard ceramic material compared to the above mentioned ceramics [8]. The B_4C reacts strongly with aluminium matrix and forms low dense and high-strength Al–B_4C composite. This Al–B_4C composite has extensive applications in the nuclear field as a fuel storage tank material due to high neutron absorption property [9]. Also, this material composition finds application in Armor plates due to light weight and high strength [10].

MMCs are fabricated by different processes such as powder metallurgy (P/M), spray depositions, squeeze infiltration, mechanical alloying and casting routes [2]. Among these processes, P/M technique is the most efficient process to make MMCs with required properties. The P/M route involves various fabrication steps such as powder blending or mixing, compacting, sintering, and secondary processes. The major problem of P/M technique is that parts are porous in nature. Several secondary processes are available to improve the mechanical properties of P/M parts by reducing or eliminating the porosity. Among that, forging is accepted as an economic and effective method for increasing the density as well as the mechanical properties through the promotion of homogeneous structures [11].

An extensive literature review has been performed in the area of workability behavior of Al–B_4C composites. Abenojar et al. [12] optimized the ball milling process parameters by measuring apparent density and flow rate for every 2 h of milling to obtain homogenize composite with higher green density. Moreover, the authors found that the optimized sintering condition is 635 °C in an argon atmosphere condition. Abdullah et al. [13] investigated the fabrication of Al/B_4C composites by powder metallurgy route using fine powder to get homogeneous micro structure. They reported that the density and hardness increases with increasing milling time and amount of boron carbide in the composite. Narayanasamy et al. [14] defined the term workability for powder metallurgy

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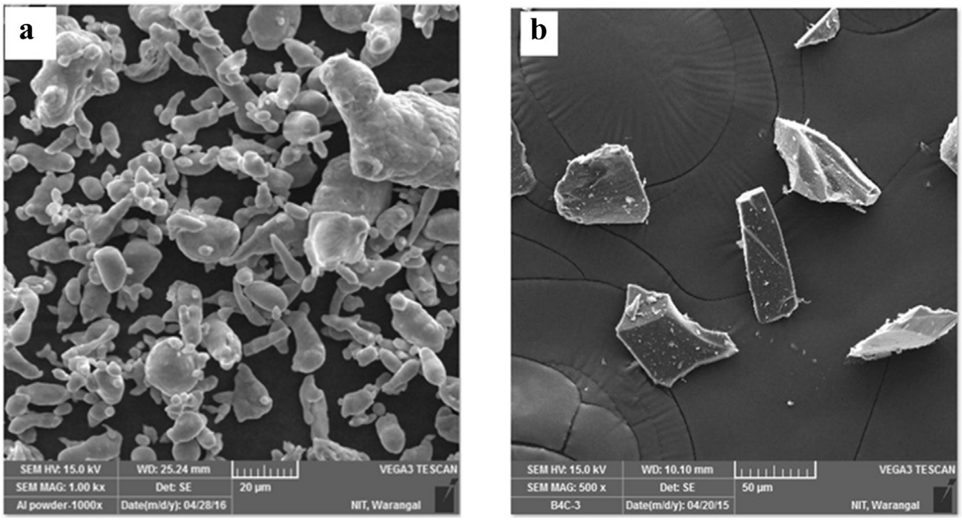

Fig. 1. SEM photograph of (a) Aluminum (b) Boron carbide.

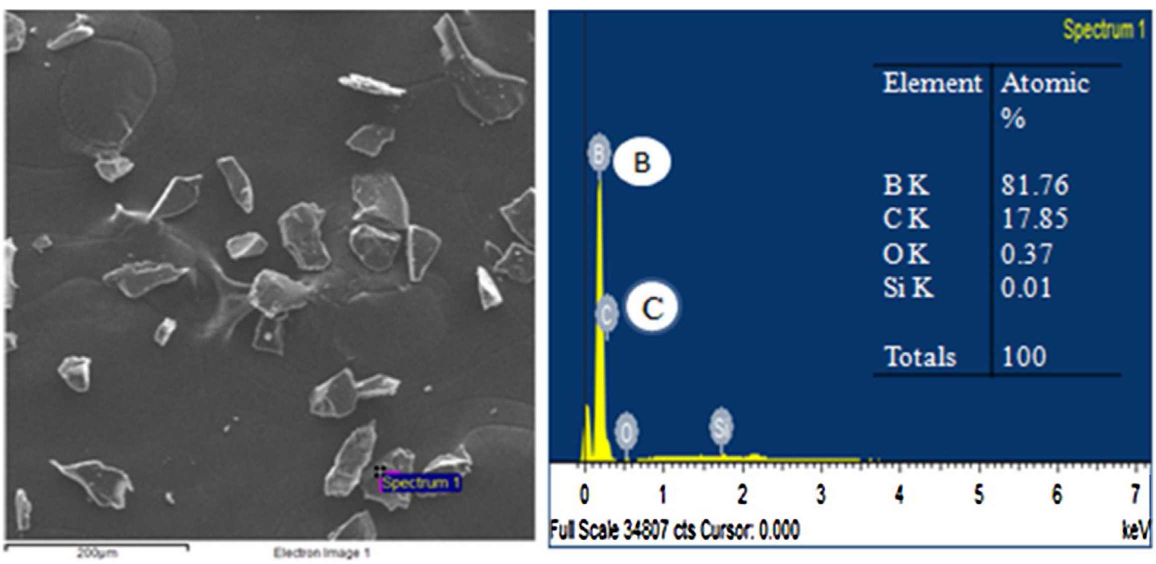

Fig. 2. EDX analysis of B_4C.

material as a measure of the deformation that a material can with stand prior to the failure in the forming process. They investigated the workability behavior of Al–Fe composites under the tri-axial stress condition and observed that there is a change in formability behavior due to various amounts and size of iron particles for different aspect ratios. Abdel-Rahman and El-Sheikh [15] investigated the effect of mean stress and effective stress on the workability factor of powder metallurgy compacts in upsetting process. Also, they investigated the effect of relative density on the formability limit of powder compacts. Vujovic and Shabaik [16] proposed forming limit criterion by stress formability index, which relates the hydrostatic stress and effective stress in the metal working processes. Tensile, compression, and torsion tests were performed to determine the forming limit curves.

Many authors have reported the mechanical properties of aluminium matrix composites (AMCs) reinforced with ceramic particles fabricated at room and high temperatures. However, the studies related to the workability and the densification behavior of the sintered Al–B_4C composite during hot forming is limited. The present investigation is focused on the study of workability and densification behavior of porous Al–B_4C composite preforms during hot upsetting. Al–B_4C is one of the high performance metal matrix composites used in industries. Al–B_4C composite is used as nuclear fuel storage tank material for storing nuclear waste in the nuclear industry due to high neutron absorption property and used as neutron shielding material. It also finds the application in hard disc substrates and brakes due to the high wear resistance property. It is also used as armor plates for high ballistics performance. Generally, the nuclear tanks, armor plates, etc. are manufactured by forming process hence the forming limit of Al–B_4C needs to be investigated for better formability. Therefore, due to the industrial significance attached to this composite, a detailed investigation on the workability and densification of sintered Al–B_4C composite preforms have been done at the elevated temperatures.

, and it was found to be homogeneous. The green compacts of 15 mm diameter and height were prepared by using hydraulic press (see Fig. 4

2. Experimental procedures

Atomized aluminium powder (Al) of particle size 325 mesh size was used as matrix material and its 99% purity with a maximum