Hot Compression and Processing maps of Magnesium reinforced with Boron Nitride Nano-composites

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Abstract. Hot compression analysis of Magnesium/Boron nitride nanocomposites were investigated with the help of UTM attached with Furnace having a capacity of 100 KN. The tests were conducted from 0.001–1 s—1 strain rate and 200–450°C temperature with an interval of 50°C. The Dynamic Material Model (DMM) is used to obtain the flow curves and processing maps and optimum hot-working conditions. The optical and scanning electron microscopes are used to analyse the microstructure of the materials. The results illustrated in relation to the material damage and structural change of the samples are varied according to the environments. It was demonstrated that the correct microstructure is also associated with the microstructure observed.

1. Introduction

An attention towards new magnesium materials in present years is increasing due to its weight-saving capabilities, high damping effect, excellent machinability and good castability in aerospace and auto body build domains. The major drawback of magnesium is its scarcity of slip in hexagonal closed packed structures and weak ductility at room temperature resists the extensive use in various applications [1, 2]. Modification in textures by the addition of nanoscale reinforcements improves the property of Mg at room temperature by activating non-basal slip systems [3]. Boron Nitride (BN) is a new material for nanoscale reinforcement material due to its excellent mechanical and thermal properties because of the the high melting point, low density, high thermal conductivity and better electrical resistivity [4 - 6].

A theoretical approach using Dynamic Material Model (DMM) and Processing Map Technology (PMT) is used to optimize materials by controlling the microstructure and hot worked material properties. Also, the quality and reliability of the product is improved [7-9].
In the present research work, nano-sized BN particulates are incorporated with Mg using microwave sintering powder metallurgy technique to determine the tribology behavior of Mg-BN nano composites at various temperatures and strain rates.

2. Experimentation
The matrix content used in this work is 98.5% pure magnesium powder of 60–300 μm sizes and 50nm boron nitride (BN) particles of nano-size are used for strengthening purposes. Nano scale BN volume of 0.5 wt. percent. The powder-metallurgy technology was employed to synthesize Pure Magnesium with its Nano BN-Particles reinforced composites required for current research [10, 11]. The synthesis was achieved by merging pure magnesium powder in a mechanical alloy system at 200 rpm with various fractions in volume of nano-sized BN powder within 1 hour. This ensures no damage or harm to the product during blending process. At 50 tons, the mixed Mg-powder mixture was then compacted uniaxially cold into billets of 35 mm diameter and 40 mm long. These tickets have been sintered using a two-way synthetic hybrid microwave [10, 11] process. Then, billet billets were sanded and impregnated with graphite at 400 °C to form rods by hot extrusion at 350 °C for a diameter of 8 mm.

Tests for hot compression [12] for various strains rates (0.001s⁻¹ – 1.0 s⁻¹) and temperatures (200 - 450°C) were accomplished on a FIE servo operated universal test system. The specimen size is 12 mm in height and diameter of 8 mm. The specimens are developed using split resistance heating furnace with SiC heating elements. The specimens were deformed to half the height as it is for imposing a true strain of about 0.5. In parallel to the metallographic axis, the sections of specimens crushed were cut at either end of the specimen. Optical micrographs were recorded with a nital plus methanol reagent by etching the specimens [13]. Results of flow stress at 0.5 constant strain rate for different load and temperature rates are determined for the efficiency of dissipation and flow instability. The processing maps are obtained for 0.5 strains with 0.5wt % BN nano composites. In all the hot forming processes, optical microscopy and scanning electron microscopy were used to evaluate the structural evolution and material damage of polycrystalline alloy [8].

| Strain Rate (s⁻¹) | True Strain | Temperature (°C) |
|------------------|-------------|------------------|
|                  | 200         | 250              | 300  | 350  | 400  | 450  |
| **0.001**        | 0.1         | 65.59            | 55.27| 44.95| 34.63| 26.64| 18.65|
|                  | 0.2         | 57.56            | 48.23| 38.9 | 29.57| 24.73| 17.89|
|                  | 0.3         | 40.25            | 35.12| 31.99| 25.86| 22.04| 17.21|
|                  | 0.4         | 32.23            | 28.86| 26.49| 23.12| 20.89| 16.65|
|                  | 0.5         | 25.92            | 24.13| 23.35| 21.56| 19.21| 15.85|
| **0.01**         | 0.1         | 71.11            | 60.53| 49.96| 39.38| 30.18| 22.98|
|                  | 0.2         | 62.9             | 53.99| 43.09| 34.18| 27.13| 21.08|
|                  | 0.3         | 49.83            | 41.58| 35.34| 29.09| 24.12| 19.35|
|                  | 0.4         | 39.22            | 33.35| 29.48| 25.61| 22.19| 18.57|
|                  | 0.5         | 28.17            | 26.11| 25.06| 24    | 20.76| 17.51|
| **0.1**          | 0.1         | 79.28            | 67.11| 55.94| 47.77| 38.33| 28.88|
|                  | 0.2         | 71.52            | 61.86| 52.2 | 42.54| 35.72| 26.9 |
|                  | 0.3         | 62.24            | 53.11| 44.99| 35.86| 28.52| 24.18|
|                  | 0.4         | 46.22            | 40.71| 35.21| 29.7 | 25.64| 21.57|
|                  | 0.5         | 34.79            | 31.74| 28.7 | 26.65| 22.7 | 19.75|
3. Outcomes and Discussions

3.1 The Flow curves

![Flow curves](image1)

**Figure 1.** Various strain rates flow stress curves (at 450°C).

![Flow curves](image2)

**Figure 2.** Various temperatures flow stress curves (at 1.0strain rate)
Figure 1 represents the flow stress curves for Magnesium - 0.5 wt.% Boron Nitride nanocomposites attained at 450°C for various strain rate. The curves remain consistent at 0.001s−1 and 1s−1 strain rate compare with other materials described under hot deformation behavior. Overall a steady state deformation is observed for Mg - 0.5wt.% BN nanocomposites at various strain rates. The flow stress gradually increases with increasing the rate of strain from 0.001 to 1.0 s⁻¹.

Figure 2 represents the flow curves for Magnesium - 0.5wt.% Boron Nitride nanocomposites obtained for various temperatures under the constant rate of strain of 1.0 s⁻¹. For all nanocomposites, the increase in temperature results in decreasing the flow stress and work hardening characteristic. From figure 2 the continuous decrease in flow stress, representing DRX in the material over the whole scope of rate of strain and temperatures [14].

In figure 1 and figure 2, the strain rate have a substantial effect on the rate of temperature rise. By adiabatic heating measured temperature rise obtained is optimum at 450°C and 0.1 s⁻¹ strain rate at 0.5 true strain.

3.2 The Processing Maps

The processing maps were changed by determining the processing protocol presented earlier [15,16, 17]. From the figure 3, the curve is a measure showing the efficacy of power dissipation. The shaded regions reflect flow instabilities which form the rate of power dissipation. This correlates to hot working microstructure evolution rate. The iso-efficiency contour maps remained more or less unchanged, but there was an obvious growth of instability regions around higher strain rates and temperatures and the instability zones increased. The chart showed an area with a greater degree of power dissipation. Existence of composite domain exists at 435°C to 495°C temperature range and 0.01 - 0.25  s⁻¹ strain rate range, with maximal production values of about 28 %. Another unpleasant condition arises at elevated temperatures above 500°C and high strain concentrations of 1.0 s⁻¹. Structures of the specimen indicate flow localization in some area. Processing these materials at rates of more than 1.0 s⁻¹ might not be required. Unstable regions can be noticed in two places.
3.3 Stability Zones by Microstructural Evolutions

The microstructural observation has justified the estimation of deformation stability. Figure 4 represents deformation diagram of the specimen with normal microstructures at true strain of 0.5 at 450°C and 0.1 s⁻¹ strain rate. DRX shows the complete recrystallization (hardening and cracking). The DRX materials leads finer grains along with better grains sizes compared to undeformed grains. This microstructure featured fine equally spaced, twinned grain boundaries, which occur after a DRX phase. The search space of DRX is preferred for hard working as the softening process improves workability. In DRX domain, J (dissipate power content) dissipates by grains interface dislocation generation and on the resultant J. Despite the shape and scale of grains varying during deformation, grains can be rearranged with DRX.

![Figure 4. The Dynamic recrystallization (400°C and 0.1s⁻¹ strain rate)](image)
The DRX domain is beneficial and secure for hot compression. Stretching of ellipsoids collected at 450°C for 0.1 s⁻¹ have deformed to be elongated as shown in figure 5.

Since strain rates are high, plastic deformation produces heat that is not transferred to other regions of the body but is locally dissipated. With reference to axis of principle stress, adiabatic shear bands are particularly prevalent at 45°.

By entering resin in longitudinal direction, the BN that was applied to the magnesium resin was fluid. Shear bands would be deformed on one side. Shear bands happen in different metals and alloys, particularly those that involve a low Stacking Fault Energy [18]. Shear bands afford the chance of narrowing flow paths. [19].

Shear bands action are observed for 300°C and 1.0 s⁻¹ strain rate as displayed in figure 6. With the deformation of metals and alloys, many twins are found in shear bands, which are difficult to deform. It will facilitate fracturing and instabilities, and non-homogeneous microstructures. Heat workplace conditions can be discouraged.

Particle cracking or weakness will cause the propagation of a crack through surface to interstitial voids. The cavities that are observed are possibly precipitated from nucleation which occurred at
350 °C and 1.0 s\(^{-1}\) strain rate. The effect can appear before hitting height. But the steel will still be able to bear smaller load relative to the peak potential until it approaches the end of its life cycle. When a micro crack begins to grow and spreads, it gradually becomes a macro crack [20].

![Figure 7. The SEM image of voids (350°C and 1.0s\(^{-1}\) strain rate)](image7)

![Figure 8. Interface cracking SEM image (450°C and 1.0s\(^{-1}\) strain rate)](image8)
Distinct reinforced alloy composites are more susceptible to treatment elements, such as temperature and strain level, than irreparable alloy, so that heat production at a very high strain is not easy, since plastic deformation causes local temperatures to increase, the flow rate is reduced and other plastic flow located [15,21]. This was because the plastic flux at the particulate-mature interface at 450 °C temperature is situated at 1.0 s⁻¹ strain rate, as represented in Figure 8 and hard particles in the soft matrix are presented.

4. Conclusions

The Mg/BN composites developed by the technique of powder metallurgy were tested for warm compression. A temperature between 250°C to 450°C and strain rate of 0.001–0.1 s⁻¹ were evaluated for the flow stress. Efficiency of the discharge and parameters of instability were assessed and the processing maps for 0.5 strains were developed. The material obtained ideal domains and volatility regions. The hot job domains vary markedly from those of pure magnesium. The assessment of the microstructure determines the ability to form debonding adiabatic shear bands and cause fluid instability. The super plastic and dynamic recrystallization areas were defined to match ideal working areas.

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