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Hot deformation analysis and continuum maps of AA7178 Alloy and AA7178 10% SiCp composite

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Abstract : Hot deformation characteristics of AA7178 (Al-Zn-Mg-Cu) alloy and 7178 (Al-Zn-Mg-Cu) - 10wt% SiCp composite prepared using stir cast metallurgy route were investigated by compression tests. The tests were performed at strain rates from 0.01/s to 100/s and temperatures from 100 ℃ to 400 ℃. On the basis of dynamic material model a continuum map was produced. Using this continuum map various deformation mechanism like superplasticity and dynamic recrystallization (DRX) were explainedwith validation by microstructures.

Key Words: Composite; Deformation; continuum Maps

Introduction

Some aluminum matrix composites (AMCs) are known as significant advanced materials which is reinforced with ceramic particles andutilized inautomotive, aerospace, and various structural applications. The reasons for their success are high specific strength and specific stiffness, low-density,superior dimensional stability, increased fatigue resistance, low thermal expansion, accessibility of cheaper reinforcement, ease of production [1-3]. However,existence of ceramic particulates in the matrix restricts the plastic flow, which results intocorresponding poor formability of composites in comparison of alloys. Appropriatechoice of forming parameters such asstrain rates and temperature critically affect the production of defect freematerials, which needsample experimental data and mathematical models. The workability i.e., the simplicity with which a fracture free material can be molded by plastic flow, which is effectively influenced by three main factors (i) appropriate heat treatment, (ii) successive processing using various steps and (iii) accuratedetermination of 'processing window' (such as combination of strain rate and temperature circumstances that assure defect free materials).

Hot workability is affectedby microstructure of the prepared material includingstrain, strain rate, temperature, and the condition of stress in the defected area. Therefore bulk-forming operations are generally performed under hot working conditions so that workability of any material should be high. In numerousinvestigations, the hot workability of aluminum matrix composites (AMCs) werestudied; in several cases, the fundamental equations concerning flow stress, strain rate and temperature, were analyzed in conjunction with the goalof correlationbetween microstructure (e.g., grain size, sub grain size, dislocation distribution, flow instability etc) and mechanical response (i.e., temperature normalized strain rate or ductility). Hot workability of conventionally produced alloys and AMCs werewidelyassessedearlier [4-11], thoughinadequateanalyseswere reported on the character of hot deformation includingtesting parameter of alloys and AMCs [12-16]. In general, it is difficult to estimate workability of Al based composites because the composites behave differently than the alloys. To recognize the hot workability of shaped aluminum alloys, it is important to attain a anticipated combination of properties and their microstructure, which is working and shaping of these alloys using various metal forming procedureslike tensile, torsion, compression and the effect of hot deformation parameters on the hot workability and growth of microstructures [19], Similar studies were carried out for AMCs as the processing parameters of these composites, which is different from conventional alloys, therefore the operating temperatures and rate

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**Corresponding author:(E-mail: aruna.patel27@gmail.com)* of deformation must be determined for every composite system. Various AMCs have already been studied on strain rate and temperatures conditions for the development of continuum maps related toDynamic Material Model [17,18]. "Acontinuum map is an unambiguousinterpretation of the reaction of a material, in the form of microstructure phenomenon, to the required parameters and comprises of a superimposition of a instability map and power dissipation map" [22].

The power dissipation maps are consecution maps and are understood in the form of microstructural phenomenon creatingbyconceptsdescribed in the continuum maps investigated by Gandhi and Raj [23-25], which wereestablishedbased on an atomisticalmethodology. These maps provide the restrictingstrain rate and temperature situations for generating fracture and uncertain processes. i.e., at greater strain rate and smaller temperature, void/holedevelops at the interface of hard particle/metal matrix, while at smaller strain rates and elevated temperature, wedge kinds of cracksarise at triple junctions grain boundary. At extremelyelevated strain rates, uncertaintyoccurs due to adiabatic shear band development. The schemeindicatedin the reducingcircumstances for thismethod is labelled "safe" for processing, and in this scheme, procedures of dynamic recovery (smaller strain rates and temperature) and dynamic recrystallization (greaterstrain rates and temperature) arise. Even though Raj [24]described that the dynamic recrystallization is an unwantedcharacteristic during hot working of complex shapes due to occurrence of localization of flow. Further, Gandhi [25] demonstrated that dynamic recrystallization and dynamic recoveryboth are advantageous processes during hot working of anidenticalcasern, by keeping the flow rates and stresses of work hardening significantlydown. In fact,dynamic recrystallization (DRX) was displayed to efficientlyincrease the safe working area by increasing the proper attachment for cavity nucleation at hard particle boundaries and shiftingslowly the smaller bound for wedge type crack origination at the junctions of grain boundary. Thoughthese maps provide the commoninstructions, the explanation of variousrealms in the current map should be microstructurally indorsed. AMCs, nevertheless, vary from conventional alloys, and therefore, the growing temperatures and distortion rates should be optimized for each composite system. Various different AMCs already have been studied in terms of temperatures and strain rate conditions are 1100 Al-10 vol. pct SiC [28], 2124 Al-20 vol. pct SiC [26], also the impact of volume fraction of SiCp reinforcement for 2124 AMCs are studied [16] which shows that all of them demonstratedareas of dynamic recrystallization (DRX) and super plasticity.

The proposed article is an effort to examine the hot working behavior and the impact of hot deformation on microstructure of AA 7178 and AA 2014 Al reinforced with 10vol% silicon carbide particulate. It was also concluded that flow uncertainties were found at lower temperature and greater strain rates. The composite in conjunction with 10-vol pct SiC exhibited a propensity of anomalous grain formation at smaller strains, which revealed itself as a movement in the DRX domain to decrease strain rates and the vanishing of super plasticity domains.

From the literature it is clear that Silicon oncecombinedwith aluminium alloys, which improves mechanical strength and inducegranular microstructures comprisingthick Si needle which generate brittleness cause poor workability [35].

Effect of calcium addition in 7178 aluminium alloy and its microstructural and compressive deformation behavior is studied by Mondal et.al [36]. Recently additions of ZrB2 in 7178 aluminium alloy its microstructural, mechanical and corrosion behavior is studied by Dinesh et.al [37].

continuum maps basis on Dynamic material model [17,18] are producedboth for AA 7178 alloy and AA7178+10wt%SiC as an unequivocalinterpretation of the outcome of composite and alloy in the form of microstructure phenomenon.

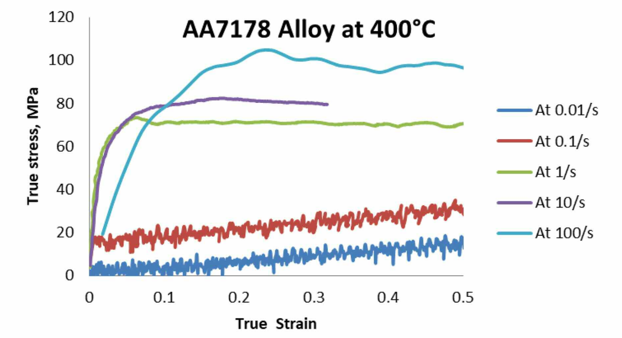
Experimental

The AA7178 (Al-Zn-Mg-Cu) alloy was prepared in an oilfired furnace. Then for fabricating composite 10wt.% Silicon Carbide particulates was dispersed through stir casting metallurgy route. Cylinder-shapedsamples with diameter and height of 10mm and 15 mm respectively for compression tests were used. Uniaxial hot compression tests wereperformed on Biss 50KN to find a steady strain rate distortion;samples were heated at each operatingtemperature andsoaked for 5min for equilibration. Fluctuation in temperature was maintained within ±2°C. The samples were compactedat a height reduction of 50%, in isothermal situation at the strain rate and temperature ranges from 0.01/s to 100/s and 100°C to 400 °C respectively. The direction of compression was parallel with axis of samples. Distortedsamples were quenched in air and segmented parallel to the compression axis, thenthe surface was cut to prepare for microstructure assessment by traditional metallographic technique and were observed in optical microscope.

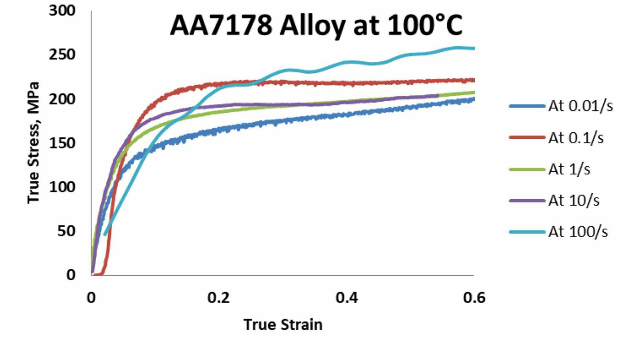
Results

Flow Curves

The flow curves of stress as function of strain were revealed in Fig.1. The stress increases on rising strain rate. Thehighestvalue of stress followed with steady state which is obtained at higher strain rate. Distortion at maximum strain rates is nearlyadiabatic inresultbecause of insufficient heat conduction due to deficientintervals. Additionally, smaller rate of disorderformation at elevated strain improves the dynamic yield stress, which carries highestvalue of stress and flow tempering. Moreover, a distorted curve at comparatively huge strain rate (> 1/s) wasexaminedin Fig1 (a), the equivalenttrendwas depicted in Fig2 (a)at everyoperating temperature. These outcomessuggest that flow alleviatingcharacterappears in matrix. Traditional dynamic recrystallization (DRX)arises in small stacking fault energy (SFE) metals during hot deformation which was reported by Prasad and Seshacharyulu [19]. They also described that recrystallization does not appear in aluminium due to its high SFE and the initialtemperingprocessis only dynamic recovery apart from that is of highly pure aluminium including some grainscomprising alloys.



3. Page 60, Fig. 1(b)



4. Page 60, Fig. 2(b)

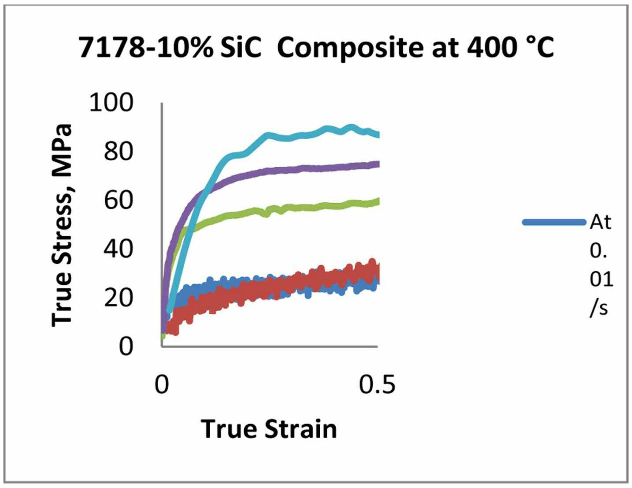
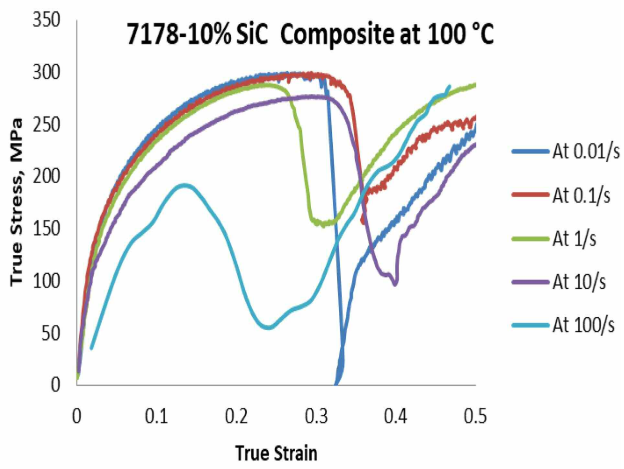


Fig. 2 (a)



Continuum Maps

A continuum map is attained by superposition of deviationineffectiveness of producing parameter with strain rate and temperature, and the deviationin instability parameter as a function of the same variable quantity. The methodology follows the dynamic material models [17–18], whichfollows the machine as source of power and the material like a power dissipater. The power dissipation maps are continuum maps and are explained in the form of microstructural methods and these concepts described in the continuum maps, which arediscussedbased on an atomistical approach previously by Gandhi and Raj [23–25].

In this article the continuum map is produced by the methods as follows;from the operation the load displacement data weretransferred to flow stress and the flow stress data were used to producecontinuum maps at 0.2, 0.3 and 0.4 strainas depicted in Fig. 3 and Fig. 4. The maps were also superimposed with instability maps indicating the safe region for hot deformation. The maps expectextremely instable and unsafe zone up to 250oC for each strain rates,while the safe zoneoffsets are presented in the range from 300oC to 400oC and strain rates from 5 x 10−1/sec to 1 x 10 −2/sec. The continuum maps indicate the greater effectiveness zone at maximum temperature and smallest strain rate. The strain rate sensitivity m is estimated as function of strain rate at each temperature. The effectiveness of power dissipation due to microstructure change [22] is then calculated from values of m at constant strain.

$\eta = 2m/m+1$-----(1)

A dimensional parameter represented by $\xi(\dot{\varepsilon})$ is as relation

$\xi(\dot{\varepsilon}) = \{\partial \ln(m/(m+1))/\partial \ln \dot{\varepsilon}\}+m > 0$------(2)

is utilized for acquiring instability maps.

Fig 3 (a) and(b)continuum map of AA7178 alloy

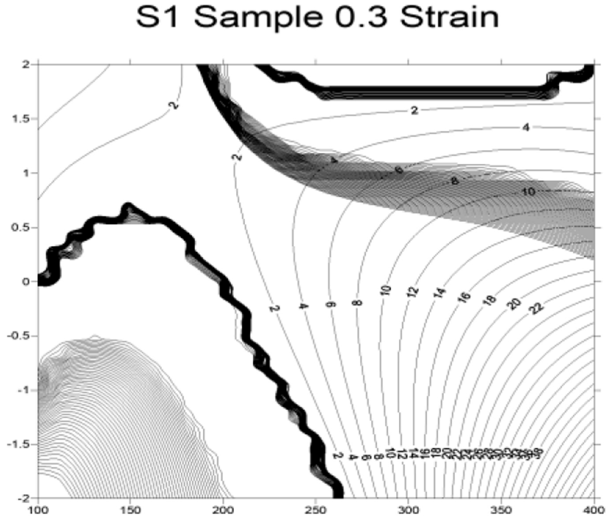


Fig 3a

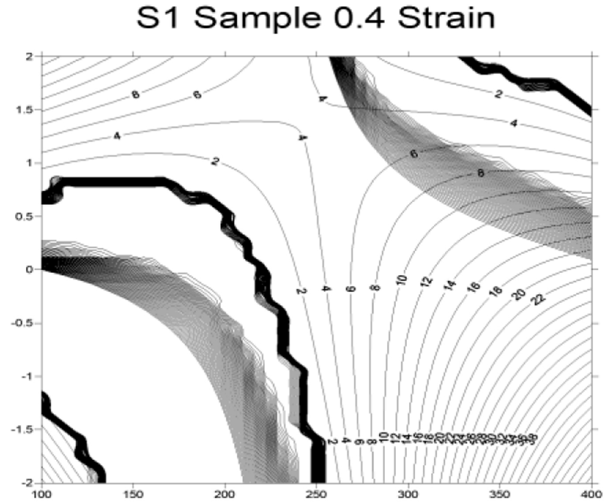


Fig 3b

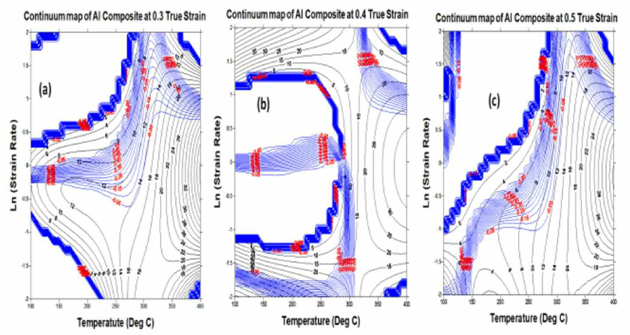


Fig 4 (a), (b)and(c)continuum map of AA7178¬¬– 10% SiC Composite

Microstructure

Fig.5 (a)and 5 (b)shows the initial microstructure of 7178 Al alloy and AA717810wt%SiCp composite. The micrograph of the alloy in as cast condition shows dendrites morphology and precipitates at the dendrite boundaries, whereas the micrograph of composite clearly shows grain structure with SiC particles uniformly distributed in the matrix.

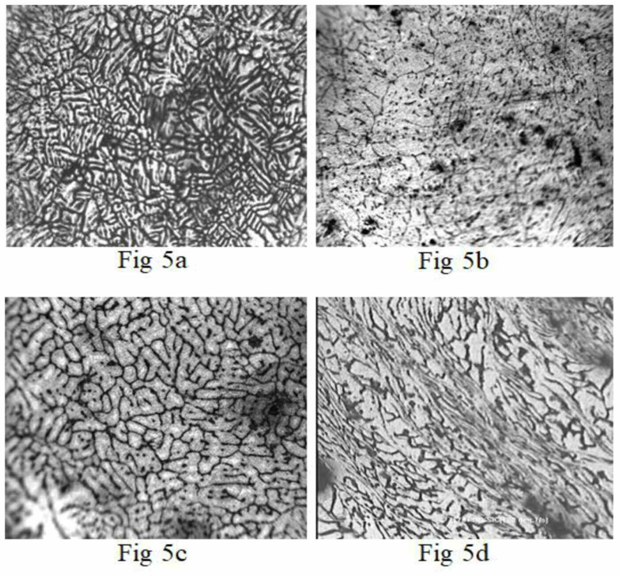


Fig 5a Fig 5b

Fig 5c Fig 5d

Fig. 5 (a) Optical micrograph of 7178 Al alloy , (b) AA7178 10%SiCp composite, (c) Micrograph showing DRX, and (d) The microstructure showing flow mechanism at temp100^{o}C and strain rate 10/s in AA7178+10%SiC composite.

Discussion

In voids of metal matrix composites mainly develop at interfaces when distorted at greater strain rates and smaller temperatures. The flow of metal composites is controlled by two keyprocedures (i) Transmission of load from ductile matrix to hard elements (ii) Micro structural conversionslike recrystallization or damage mechanism. In the maps the counter number represents power dissipation effectiveness and the shaded zones indicate the areas of flow instability. In the present composite at strain rate 0.5/s efficiency ranges from 22%-24% in temperature range 350oC-400oC, it is the zone of high temperature and high strain rate where the processing can be done. Unstable regions are obtained at temperature ranging from 100oC-300oC for all strain rate conditions.In this region the instability map and power dissipation map are almost superimposed lower efficiency area in the form of steep hills are observed which causes interfacial cracks, Because of high staking fault energy DRX can be seen at high temperature and small strain rates. It is because ofadding ceramic reinforcement to aluminum alloys the initiation of DRX during hot deformation is observed because of rising dislocation density in the matrix whether the aluminum metal matrix composites are fabricated by cast or powder metallurgy methods. Flow instability can also be seen at elevated strain rates and small temperatures. Same phenomena can also be seen in the microstructure as shown in Fig. 4. Because of increasing dislocation density the plastic flow gets restricted and contributes to the strengthening and strain hardening. DRX grains favorably nucleate in the matrix between SiC grainsconsequentlyhuge amount of plastic flow, which generatesextremedeformation density zones, which functions as dynamic recrystallization. Typical micrograph showing dynamic recrystallization is shown in fig 6. Severalresearchers have generallyproved that the addition of ceramic reinforcements into aluminum alloys encouraged the beginning of DRX during hot deformation by increasing deformation density in the matrix [15,34]. A similar phenomenon was observed in the present composites.

Conclusions

The hot operatingfeatures of AA 7178 alloy and AA7178-10vol%SiCp composites were recognized by continuum map based on Dynamic Material Model with microstructure validation. Dynamic recrystallization occurred at moderate values of dissipation effectiveness in continuum map for 7178 +10%SiC composite whereas in case of 10-vol% SiC is because ofunusual grain broadening. It may also be observed that the matrix material does not exhibit a super plasticity region in the as-hot-pressed operation. The cause for the presence of the super plasticity region in the extruded material is the small grain size generated by recrystallization after extrusion.

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