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ORIGINAL RESEARCH ARTICLE

Optimization of Process Parameters of Cyclic Expansion Extrusion Process for Effective Grain Refinement of Al-Mg-Si Alloy

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This study deals with the interaction among the cyclic expansion extrusion (CEE) process parameters, namely processing temperatures, semi-die angles, ram speeds (pressing velocities) and lubricant types on the Al-Mg-Si alloy (AA 6063). The design of experiment (DoE) with four factors and three levels was considered for the performance of experimental work using the Taguchi technique-L9 orthogonal array. Signal-to-noise (S/N) ratio and analysis of variance (ANOVA) were employed in the identification of the significant process parameters to ensure the achievement of maximum microhardness and tensile strength (UTS) as responses. Additionally, the process parameters that significantly affect the mechanical properties are ranked in the order of temperature, semi-die angle, ram speed and lubricant. The higher number of CEE passes showed a significant increase in the microhardness and tensile strength (UTS). Electron backscattered diffraction (EBSD) analysis showed a significant grain refinement in the processed sample. Specifically, effective grain refinement was achieved while processing with the semi-die angle (α = 22.5°) at 130 °C. Transmission electron microscopic (TEM) analysis was employed in the study of the sub-grain and dislocation details in the CEE processed samples.

Keywords aluminum alloy, cyclic expansion extrusion, EBSD, mechanical properties, optimization, Taguchi technique

1. Introduction

In recent years, production of ultrafine-grained (UFG)/nano-structured (NS) metallic materials has become a topic of investigation among researchers for the development of materials with improved mechanical properties (Ref 1, 2). Severe plastic deformation (SPD) techniques have been employed in the production of a UFG structure in metallic materials through the incremental application of a large strain at a temperature $< 0.5T_m$ (T_m is the melting temperature of the metal) (Ref 2, 3). Among the different SPD techniques reported (Ref 2, 4-9), the cyclic expansion extrusion (CEE) process has not been explored much. The CEE process has been developed based on the working principle of the cyclic extrusion and compression (CEC) technique which is suitable for refining the microstructure in rod-/bar-shaped specimens (Ref 10, 11).

The Taguchi technique has been employed for obtaining optimum process parameters for the achievement of better mechanical properties in several other SPD processes such as different equal channel angular pressing (ECAP) (Ref 12-14), constrained groove pressing (CGP) (Ref 15) and accumulative roll bonding (ARB) (Ref 16). Taguchi techniques based on three levels of four parameters (L9 orthogonal array) have been used in the analysis of thickness and pre-aging parameters for the attainment of superior mechanical properties in the severely deformed Al-0.2 wt.% Sc alloy (Ref 16). Analysis of variance (ANOVA) technique was used for the identification of optimized annealing temperature in accumulative roll-bonded monolithic Ti and Ti-SiC_P composites (Ref 17). The CEE process is known for several parameters, namely semi-die angles (α), processing temperatures (T), pressing ram speeds (R), types of lubricant (L) and the number of passes (n) (2-10 passes). These parameters have been taken into account in the current study of designing an efficient CEE process. In earlier studies, the authors have reported the individual effect of the number of passes (Ref 18, 19), strain rate (Ref 20) and temperature (Ref 21, 22) on the microstructural and mechanical properties of a CEE processed sample. The literature addressing the determination of the most impactful process parameters and their respective influence on mechanical properties in severe plastic deformation, particularly within the context of the CEE process, is notably scarce.

In this work, an ANOVA technique was used to locate the significant process parameters for obtaining improved mechanical properties. A statistical "F-test" in which the statistic under null hypothesis has an F-distribution was employed for the optimization of the process parameters. It is often used in the identification of the model that best fits the population from

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