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DEPARTMENT OF MECHANICAL ENGINEERING

TITLE OF THESIS: THERMOMECHANICAL PROCESSING OF SPARK PLASMA SINTERED ALUMINUM POWDER METALLURGY ALLOYS VIA ASYMMETRIC ROLLING AND UPSET FORGING

TIME/DATE: 9:00 am, Tuesday, December 3, 2019

PLACE: Room 3107, The Mona Campbell Building, 1459 LeMarchant Street

EXAMINING COMMITTEE:

Dr. Lukas Bichler, Department of Mechanical Manufacturing, University of British Columbia (External Examiner)

Dr. Stephen Corbin, Department of Mechanical Engineering, Dalhousie University (Reader)

Mr. Ian Donaldson, GKN Sinter Metals, USA (Reader)

Dr. Paul Bishop, Department of Mechanical Engineering, Dalhousie University (Supervisor)

DEPARTMENTAL REPRESENTATIVE: Dr. Dominic Groulx, Department of Mechanical Engineering, Dalhousie University

CHAIR: Dr. Wenda Greer, PhD Defence Panel, Faculty of Graduate Studies

ABSTRACT

The research in this study was completed to investigate the effects of thermal-mechanical working on spark plasma sintered (SPS) powder metallurgy (PM) preforms. Two alloys (PA2219 and an Al-Sc-Zr ternary) were considered as were two means of working – asymmetric rolling (ASR) and upset forging. To gain a firm understanding of the fundamental elements of ASR and ultimately deduce the best rolling parameters for the SPS PM alloys, research in this area commenced with studies on the well-known wrought aluminum alloy 6061. Results indicated that the utilization of a higher velocity ratio as well as a small initial thickness of the sample imparted gains in mechanical properties to the finished product. Meanwhile, changes to roller velocities and rolling direction were found to be insignificant. EBSD analysis revealed that the microstructure became more homogenized with a reduction in the number of passes. The findings from preliminary studies on AA6061 were then used to process the SPS PM alloys. The rolling schedules resulted in full densification of the sintered Al-Sc-Zr billets while $Al_3(Sc,Zr)$ precipitates observed via transmission electron microscopy (TEM) in the sintered preforms were seemingly unaffected by the rolling process. Generally, decreases in the rolling temperature yielded marginal gains in mechanical properties. The Al-Sc-Zr alloy sintered at 500^{o}C and rolled at 200^{o}C exhibited the highest concentration of low angle grain boundaries (LAGBs) and the most desirable combination of hardness and tensile properties. In forging trials, all strains and strain rates were found to impart full densification of the Al-Sc-Zr preforms. Interestingly, the lowest forging strain considered (0.4 mm/mm) imparted sizable improvements in tensile properties. In particular, tensile ductility was ~40x greater than that measured in the as-sintered counterpart. However, excessive plastic strain (1.6) fostered dynamic recrystallization and possibly the formation of adiabatic shear bands that invoked declines in tensile properties. Strain rate was also found to be influential as lower rates enhanced recrystallization prompting reductions in yield strength and minor gains in ductility.

For the PA2219 PM alloy, forging achieved full densification of sintered preforms. In addition, the forging process imparted gains in the tensile properties. Further improvements in tensile strength were realized in the heat treated (T87) specimens. For instance, the yield strength of the forged-T87 products were some 40-60% higher than counterpart specimens tested in the as-forged (T1) state. The optimum tensile properties were obtained for the specimen SPS processed 550^{o}C and Forged (T87) at 500^{o}C (YS=354MPa, UTS = 466MPa, Elongation =13%). One of the critical observations made was that a continuous oxide film was present in the microstructure of the spark plasma sintered billet. Fortunately, this tenacious layer was disrupted through upset forging. The discretization of this oxide network would have contributed towards the improved tensile properties in the forged products especially the ductility.