EFFECT OF STRAIN PATH CHANGE ON STATIC RECRYSTALLIZATION BEHAVIOR OF COLD DEFORMED Mg-6Al-3Sn MAGNESIUM ALLOY

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JANUARY 2020

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by

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Submitted

in fulfilment of the requirements of the degree of Doctor of Philosophy

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

JANUARY 2020

CERTIFICATE

This is to certify that the thesis entitled **"Effect of Strain Path Change on Static Recrystallization Behavior of Cold Deformed Mg-6Al-3Sn Magnesium alloy"** being submitted by **Mr. Gaurav** to the Indian Institute of Technology Delhi for the award of the degree of **DOCTOR OF PHILOSOPHY** is a record of bonafide research work carried out by him under our supervision and guidance. The matter presented in this thesis has not been submitted, in part or in full to any other University or Institute for the award of any degree or diploma.

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Acknowledgements

I express my deep sense of indebtedness to **Prof. Rajesh Prasad** and **Prof. Jayant Jain** for his excellent careful and encouraging guidance, teaching, supervision throughout the tenure of my research work. His intense humane, motivational speech and understanding personality has left an indelible impression upon me.

I sincerely acknowledge all the faculty members of the department for their continuous support, technical as well as moral. I gratefully acknowledge Prof. Sudhanshu S. Singh from IIT Kanpur and his Ph. D student R. Sharvesha for helping in EDS and EBSD results.

I gratefully appreciate the help of Mr. S.B. Prasad for helping me during rolling and forging. In addition, I am thankful to Mr. Kuldeep Sharma and Mrs. Kumud Arora from IIT Delhi, India to assist me in the scanning electron microscopy work (SEM). I am also thankful to office staff of our department for administrative help. I thankfully acknowledge my friends and colleagues from the bottom of my heart for their moral support. At last, I thank all my labmates for standing with me at the good and bad times. I will never forget their constant encouragement and moral support throughout my stay at IIT, Delhi.

I gratefully acknowledge my research committee members: Prof. Puneet Mahajan, Prof. S. Aravindan, Dr. Vikrant Tiwari for their insightful comments and valuable suggestions.

I am immensely glad to value the unconditional love and encouragement provided by my parents and wife. Without their support, I could not have reached this far. At the last, I dedicate this thesis to my late father.

Gaurav

Abstract

Grain refinement is an effective approach to improve the mechanical properties and formability of magnesium and its alloys. Dynamic recrystallization (DRX) and static recrystallization (SRX) are the two important processes by which finer grain size can be achieved in the materials. In the present work, effect of strain path changes on SRX behaviour of cold deformed Mg-6Al-3Sn (AT63) magnesium alloy has been extensively studied. The solutionized AT63 alloy was deformed at an ambient temperature by three different routes; Unidirectional cold rolling (UDR), Clock cross rolling (CCR) and forging. The cold deformed samples were subsequently annealed at temperature ranging from 200°C to 400°C. The main purpose of this study was to characterize the microstructural evolution as a function of annealing temperature. Since, AT63 magnesium alloy has two types of precipitates $Mg_{17}Al_{12}$ and Mg_2Sn; there is always competition between precipitation and recrystallization that decides the rate of kinetics of recrystallization. Microstructural characterization such as nucleation sites of grains, grain morphology and concurrent precipitation was analysed thoroughly under specified deformation and heat treatment conditions. Effect of annealing temperatures on the recrystallized fraction and kinetics was also evaluated for the UDR, CCR and forged samples.

The experimental results from this research show that the prior grain boundaries and twins are the main nucleation sites of recrystallization. Recrystallization at lower temperatures is found to be incomplete even at longer holding times. It is attributed to concurrent precipitates that develop during annealing which arrest the movement of grain boundaries. However, at higher temperatures, the amount of concurrent precipitates is lesser and hence does not interfere with the recrystallization. In other words, recrystallization is completed rapidly before the occurrence of precipitation at higher annealing temperatures. The above results are common for all three

processed UDR, CCR and forged samples. However, the kinetics of recrystallization is relatively faster for UDR and slower for CCR samples under the same annealing conditions. It can be assumed that due to the stored energy in the materials, initial texture and distribution and morphologies of concurrent precipitates is relatively different.

सार

मैग्नीशियम और इसके मिश्र धातुओं के यांत्रिक गुणों और संरचना में सुधार के लिए ग्रेन शोधन एक प्रभावी तरीका है। डायनामिक रीक्रिस्टलाइज़ेशन (डीआरएक्स) और स्टैटिक रीक्रिस्टलाइज़ेशन (ऐसआरएक्स) दो महत्वपूर्ण प्रक्रियाएँ हैं जिनके द्वारा सामग्री में छोटा सा ग्रेन का आकार हासिल किया जा सकता है। वर्तमान कार्य में, ठंडे विकृत Mg-6Al-3Sn (एटी 63) मैग्नीशियम मिश्र धातु के ऐसआरएक्स व्यवहार पर तनाव पथ परिवर्तन के प्रभाव का बड़े पैमाने पर अध्ययन किया गया है। तीन अलग-अलग मार्गों से परिवेशी तापमान पर घटी हुई AT63 मिश्र धातु को हल किया गया; यूनिडायरेक्शनल कोल्ड रोलिंग (यूडीआर) , क्लॉक क्रॉस रोलिंग सीसीआर और फोर्जिंग। ठंड विकृत नमूने बाद में 200 डिग्री सेल्सियस से 400 डिग्री सेल्सियस तक के तापमान पर तापित थे। इस अध्ययन का मुख्य उद्देश्य तापमान के एक समारोह के रूप में मॉइक्रोस्ट्रक्चर विकास को चिह्नित करना था। चूंकि, एटी 63 मैग्नीशियम मिश्र धातु में दो प्रकार के प्रेसिपिटेट $Mg_{17}Al_{12}$ और Mg_2Sn हैं; प्रेसिपिटेट और रीक्रिस्टलाइज़ेशन के बीच हमेशा प्रतिस्पर्धा होती है, जो रीक्रिस्टलाइज़ेशन के कैनेटीक्स की दर तय करती है। सूक्ष्म विकृति लक्षण जैसे ग्रेन के न्यूक्लिएशन साइट, ग्रेन आकारिकी और समवर्ती प्रेसिपिटेट का निर्दिष्ट विरूपण और ताप उपचार स्थितियों के तहत अच्छी तरह से विश्लेषण किया गया था। यूडीआर, सीसीआर और फोर्जिंग नमूनों के लिए रीक्रिस्टलाइज अंश और कैनेटीक्स पर तापमान के प्रभाव का भी मूल्यांकन किया गया था।

इस शोध के प्रयोगात्मक परिणामों से पता चलता है कि पूर्व ग्रेन की सीमाएँ और ट्विन्स रीक्रिस्टलाइज़ेशन के प्रमुख न्यूक्लियेशन स्थल हैं। कम तापमान पर क्रिस्टलीकरण अधिक समय तक रखने पर भी अधूरा पाया जाता है। इसे समवर्ती प्रेसिपिटेटस के लिए जिम्मेदार ठहराया जाता है जो ग्रेन के दौरान विकसित होते हैं जो ग्रेन की सीमाओं के मूवमेंट को अबरुद्ध करते हैं। हालांकि, उच्च तापमान पर, समवर्ती अवक्षेप की मात्रा कम होती है और इसलिए रीक्रिस्टलाइज़ेशन के साथ हस्तक्षेप नहीं करता है। दूसरे शब्दों में, उच्च तापमान वाले तापमान पर प्रेसीपीटशन की घटना से पहले रीक्रिस्टलाइज़ेशन तेजी से पूरी होती है। उपरोक्त परिणाम सभी तीन संसाधित यूडीआर, सीसीआर और जाली नमूनों के लिए आम हैं। हालांकि, पुनरावर्तन के कैनेटीक्स यूडीआर के लिए अपेक्षाकृत तेज़ हैं और सीसीआर नमूनों के लिए धीमी गति से एक ही अनलिंग शर्तों के तहत। यह माना जा सकता है कि सामग्री में संग्रहीत ऊर्जा के कारण, प्रारंभिक बनावट और वितरण और समवर्ती प्रेसिपिटेटस के आकारिकी अपेक्षाकृत भिन्न हैं।

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Symbols and Abbreviations

Extrusion direction	ED
Severe plastic deformation	SPD
Forging Direction	FD
Static recrystallization	SRX
Rolling Direction	RD
Dynamic recrystallization	DRX
Transverse Direction	TD
Normal Direction	ND
millimeter	mm
micrometer	μm
Kilo-electron volt	KeV
Continuous Dynamic recrystallization	CDRX
Continuous recrystallization	cSRX
Discontinuous recrystallization	dSRX
Twin assisted SRX	TSRX
Exponent	exp
Multi directional forging	MDF
Equal channel angular pressing	ECAP
Grain orientation spread	GOS
Inverse pole figure	IPF
Low angle grain boundaries	LAGB
High angle grain boundaries	HAGB

Critical resolved shear stress	CRSS
Electron back-scattered diffraction	EBSD
Scanning electron microscope	SEM
Stacking fault energy	SFE
X-ray diffraction	XRD
Orientation imaging microscopy	OIM
Hexagonal closed packed	HCP
Unidirectional cold rolled	UDR
Clock cross rolled	CCR