



ARL-TN-1015 • MAY 2020



Heterogeneous Mechanical Behavior of Equal Channel Angular Extrusion (ECAE)-Processed Magnesium AZ31-B

by Daniel T Casem

Approved for public release; distribution is unlimited.

NOTICES

Disclaimers

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.



Heterogeneous Mechanical Behavior of Equal Channel Angular Extrusion (ECAE)-Processed Magnesium AZ31-B

Daniel T Casem

Weapons and Materials Research Directorate, CCDC Army Research Laboratory

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY) May 2020		2. REPORT TYPE Technical Note		3. DATES COVERED (From - To) 1 August–30 September 1017	
4. TITLE AND SUBTITLE Heterogeneous Mechanical Behavior of Equal Channel Angular Extrusion (ECAE)-Processed Magnesium AZ31-B				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Daniel T Casem				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) CCDC Army Research Laboratory ATTN: FCDD-RLW-PC Aberdeen Proving Ground, MD 21005-5069				8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TN-1015	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES ORCID ID: Daniel Casem, 0000-0002-0475-0226					
14. ABSTRACT A series of low-rate uniaxial-stress compression tests were performed on magnesium AZ31-B processed by equal channel angular extrusion using the 4B _C route. These tests show a large variation in the mechanical response from samples machined from different locations in the billet. The reason for the heterogeneity has not been conclusively established.					
15. SUBJECT TERMS magnesium alloys, equal channel angular extrusion, severe plastic deformation processing, mechanical testing, anisotropic plasticity					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 15	19a. NAME OF RESPONSIBLE PERSON Daniel T Casem
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (Include area code) (410) 306-0972

Contents

List of Figures	iv
Acknowledgments	v
1. Introduction	1
2. Experiments	1
3. Results	3
4. Discussion and Conclusion	5
5. References	6
List of Symbols, Abbreviations, and Acronyms	7
Distribution List	8

List of Figures

Fig. 1	Sketch of the original billet. All samples were taken from the center section shown by the dashed region.....	2
Fig. 3	Stress–strain curves for all 25 repeated experiments.....	3
Fig. 4	Stress–strain curves from samples along the diagonal from the center of the billet to the lower-right corner.....	3
Fig. 5	Stress–strain curves from samples along the vertical path from the center straight to the bottom.....	4
Fig. 6	Stress–strain curves from samples along the right-hand side of the lower-right quadrant.....	4
Fig. 7	Stress–strain curves from samples along the horizontal path from the center straight to the right edge.....	4

Acknowledgments

The author would like to thank Mr Kevin Taylor for his help preparing and testing the samples used in this study.

1. Introduction

Magnesium (Mg) alloys have potential armor applications and have been extensively studied under the Materials in Extreme Dynamic Environments Collaborative Research Alliance (MEDE CRA). One of the materials studied was Mg AZ31-B 4B_C, which is processed using equal channel angular extrusion (ECAE).¹ In this process, a square cross-section billet is pressed through a 90° die that severely deforms the material and refines its grain size without appreciably changing the dimensions of the part. The 4B_C route denotes that four passes are made through the die, rotating the part 90° incrementally with each pass.

Because of its fine grain size, approximately 5 μm, and due to the interest of the MEDE CRA, this material was evaluated as a candidate for an ultra-high-strain-rate testing program at the US Army Combat Capabilities Development Command (CCDC) Army Research Laboratory (ARL). This program used miniature Kolsky bar techniques^{2,3} and required small samples (tens to hundreds of microns). Because of this, the small grain size was attractive. The first step in the evaluation was to ensure the material was sufficiently homogeneous that variations in material behavior due to strain-rate would not be overwhelmed by typical sample-to-sample variation in material properties due to spatial variations throughout the billet. Unfortunately, it was found that indeed this was not the case, and testing on this material for the aforementioned CCDC ARL program was discontinued. However, there was interest in this finding by the MEDE CRA, and so this report documents the limited work that was performed.

2. Experiments

The material and its processing are described in Krywopuska et al.⁴ The original billet was 150 mm long and 18 × 18 mm in cross section. All samples were machined from the center cross section of the billet, as shown in Fig. 1. A total of 100 samples were made by electro discharge machining (EDM) in a grid pattern, as shown in Fig. 2. An x–y system of coordinates is introduced, and samples are labeled by column and row in an obvious way. Although the extrusion direction is known, the relation between the x- and y-directions to the processing route is unknown.

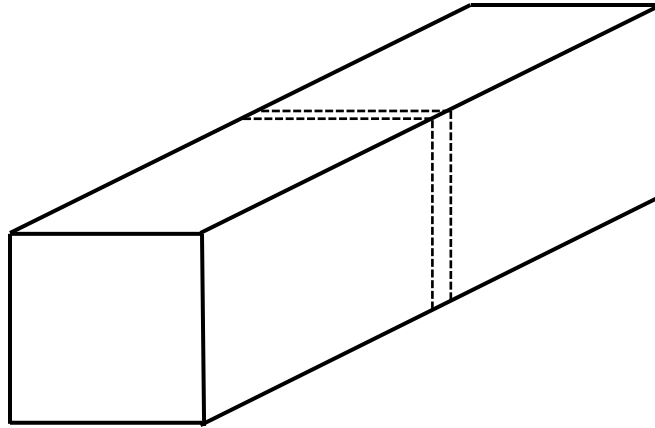


Fig. 1 Sketch of the original billet. All samples were taken from the center section shown by the dashed region.

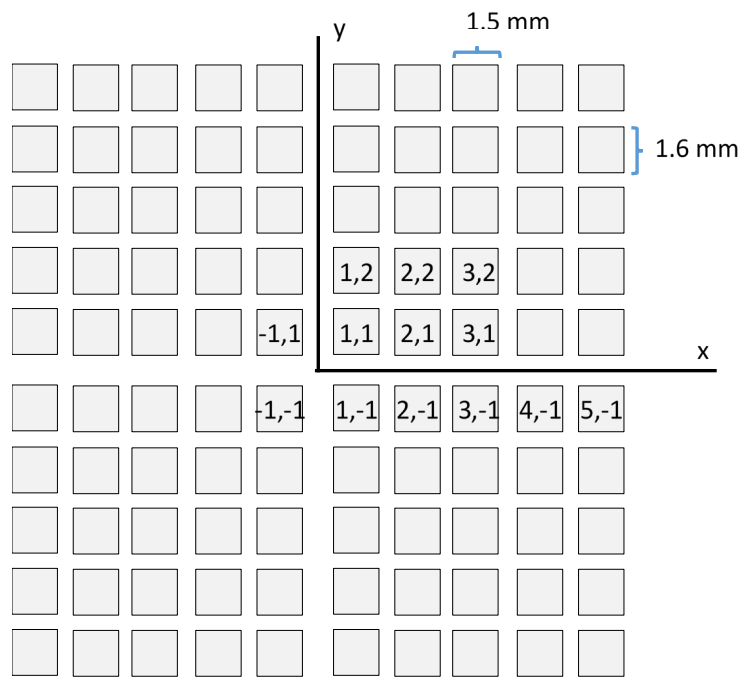


Fig. 2 Location of samples with respect to the lateral directions. It is not known how directions x and y relate to the processing route. Individual samples are labeled by column number and row number, in the pattern established in the figure (note there is no row “0” or column “0”).

Samples approximated cubes, nominally $1.5 \times 1.6 \times 1.4$ mm. All samples were cut slightly oversized and then polished on all six faces to remove the EDM finish. The different dimensions were used to keep track of orientation. All samples were tested in the extrusion direction (1.4-mm gage length). Although experiments in the other two directions were initially planned, these were canceled when testing with this material was discontinued.

Uniaxial stress compression tests were performed in a servo-hydraulic load frame. Load was measured with a load cell, and specimen deformation was inferred from the known cross-head displacement (no correction for machine compliance has been applied to these data). Samples were lubricated using molybdenum disulfide grease. The nominal strain-rate for each test is 0.001/s.

3. Results

A total of 25 experiments were performed using all of the samples from the lower right quadrant in Fig. 2. All of the stress–strain curves are shown in Fig. 3. Select data, along certain paths on which trends might be expected, are plotted in Figs. 4–7.

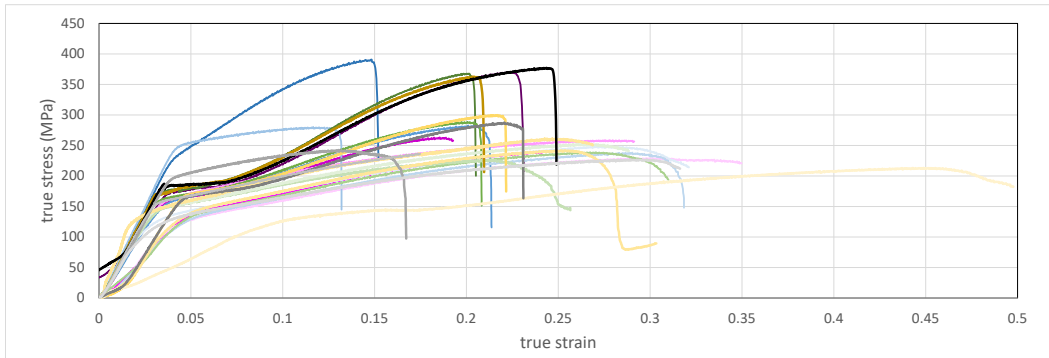


Fig. 3 Stress–strain curves for all 25 repeated experiments

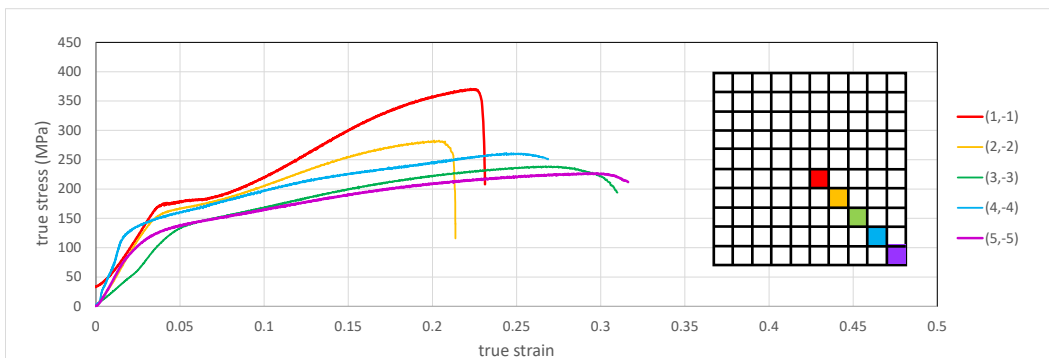


Fig. 4 Stress–strain curves from samples along the diagonal from the center of the billet to the lower-right corner

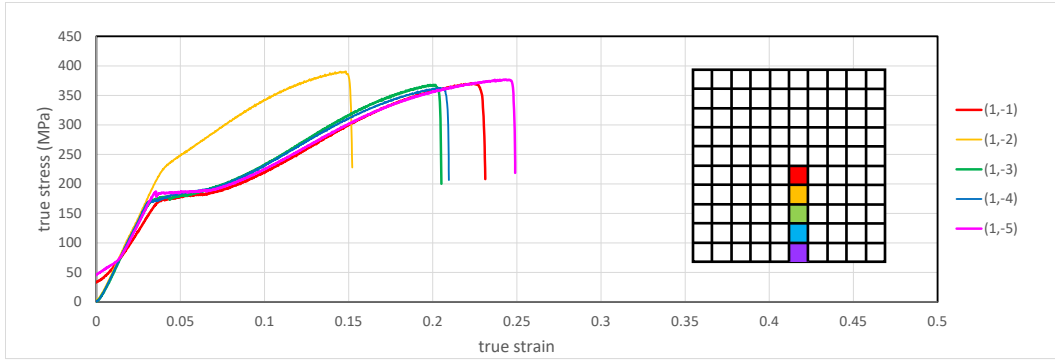


Fig. 5 Stress–strain curves from samples along the vertical path from the center straight to the bottom

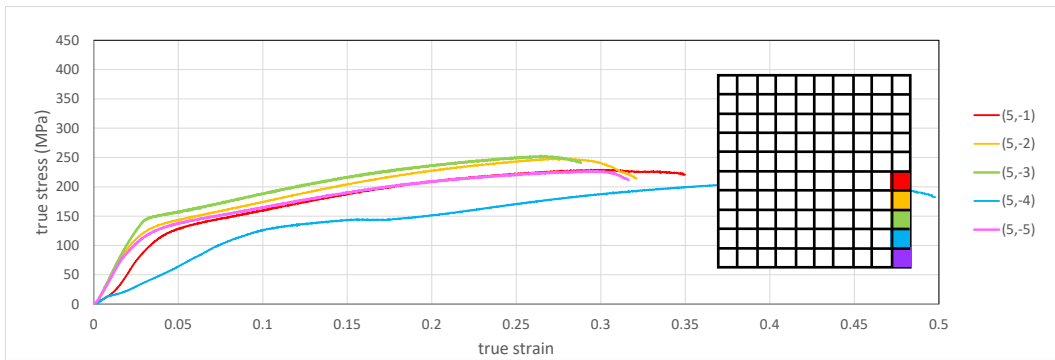


Fig. 6 Stress–strain curves from samples along the right-hand side of the lower-right quadrant

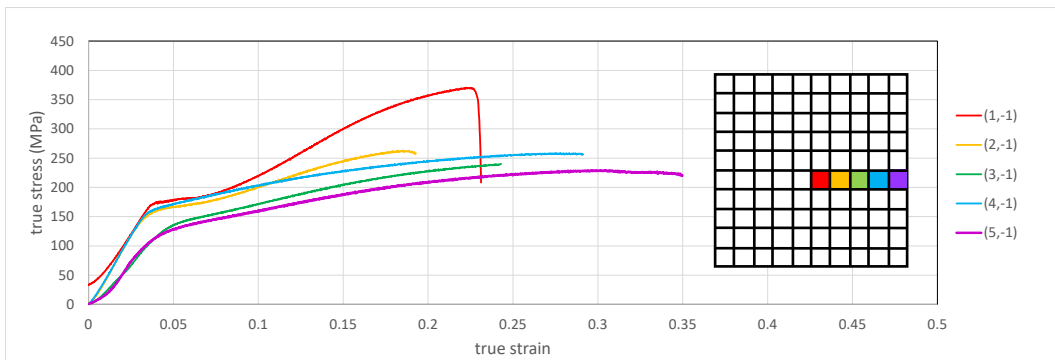


Fig. 7 Stress–strain curves from samples along the horizontal path from the center straight to the right edge

4. Discussion and Conclusion

These experiments show significant variation in the mechanical behavior of Mg AZ31-B processed by 4B_C ECAE. Mg AZ31-B is known to be highly anisotropic due to its hexagonal closest packed structure. This suggests that the variation observed here might be due to variation in crystallographic orientation between samples rather than a true variation in material behavior. A similar evaluation was made by the author and co-workers on tantalum processed by ECAE, and although an unusual specimen size effect was found, the uniformity of mechanical behavior between samples was good.⁵ As a body-centered cubic metal, tantalum is largely isotropic.

5. References

1. Furukawa M, Horita Z, Nemoto M, Langdon TG. Review: processing of metals by equal-channel angular pressing. *Journal of Materials Science*. 2001;36:2835–2843. <https://doi.org/10.1023/A:1017932417043>.
2. Casem D, Grunschel S, Schuster B. Normal and transverse displacement interferometers applied to small diameter Kolsky bars. *Exp Mech*. 2012;52:173–184. <https://doi.org/10.1007/s11340-011-9524-x>.
3. Casem D, Ligda J, Walter T, Darling K, Hornbuckle B. Strain-rate sensitivity of nanocrystalline Cu–10Ta to 700,000/s. *J Dyn Behav Mater*. 2020;6:24–33. <https://doi.org/10.1007/s40870-019-00223-w>.
4. Krywopuska NM, Williams CL, Kecskes JL, Weihs TP. Characterization of spalled AZ31B processed by ECAE. *Materials Science and Engineering A*. 2019;767.
5. Casem DT, Magagnosc D, Ligda J, Walter T, Schuster B. Specimen size effects on the compressive stress–strain response of equal channel angular extrusion (ECAE) tantalum. Aberdeen Proving Ground (MD): CCDC Army Research Laboratory (US); 2019 June. Report No.: ARL-TR-8729.

List of Symbols, Abbreviations, and Acronyms

ARL	US Army Combat Capabilities Development Command (CCDC) Army Research Laboratory
CCDC	US Army Combat Capabilities Development Command
ECAE	equal channel angular extrusion
EDM	electro discharge machining
MEDE CRA	Materials in Extreme Dynamic Environments Collaborative Research Alliance
Mg	magnesium

1 DEFENSE TECHNICAL
(PDF) INFORMATION CTR
DTIC OCA

1 CCDC ARL
(PDF) FCDD RLD CL
TECH LIB

1 CCDC ARL
(PDF) FCDD RLW PC
D CASEM