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14. ABSTRACT
This project processed multilayered materials with alternating titanium and AZ31 magnesium alloy through accumulative roll bonding. The samples with 3, 5, and 7 layers were obtained. These samples were characterized microstructurally and mechanically using optical microscope, scanning electron microscopy, and debonding testing. The results show that titanium grains were heavily elongated along the rolling direction and just slightly elongated along the transverse direction; AZ31 magnesium alloy layers had equiaxed grains. There are smaller grains in the

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Report Title

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Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Book

TOTAL:

Received Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Chin shih Hsu	0.40	
FTE Equivalent:	**0.40**	
Total Number:	**1**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Qizhen Li	0.10	
FTE Equivalent:	**0.10**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

The content is in the attached report file.

Technology Transfer

Final Scientific/Technical Report

Proposal Number: **65823MSII**

Agreement Number: **W911NF1410598**

Proposal Title: Nanostructured Mg AZ31/Ti64 Multilayer Thin Films: Mechanism of Twin-Assisted Ductility and Strength

Report Period Begin Date: **10/01/2014**

Report Period End Date: **06/30/2015**

Principal Investigator: **Qizhen Li**

Name of Recipient: **Washington State University**

1. Foreword:

Accumulative rolling bonding (ARB) [1] is broadly used to process metallic materials including pure metal [2,3], alloy [4,5], two different metals [6,7], and three different metals [8,9]. It is meaningful to investigate the production and properties of multilayered materials based on titanium and magnesium since both are light metals and the produced multilayered materials would be attractive as lightweight and high strength materials.

2. List of Appendixes, Illustrations and Tables (if applicable)

A number of illustrations appear in the following section on "Summary of the most important results". A separate list is not given in this section to avoid the repetition.

3. Statement of the problem studied

This project aimed to process multilayered materials with alternating titanium and AZ31 magnesium alloy through accumulative roll bonding; produce multilayered samples with different numbers of layers; characterize the samples microscopically to understand the layered structure, the internal microstructure of individual layers, and the interfacial structure; and characterize the strength of the interfacial bonding. The microstructural and mechanical characterizations were realized through using optical microscope, scanning electron microscopy, and debonding testing.

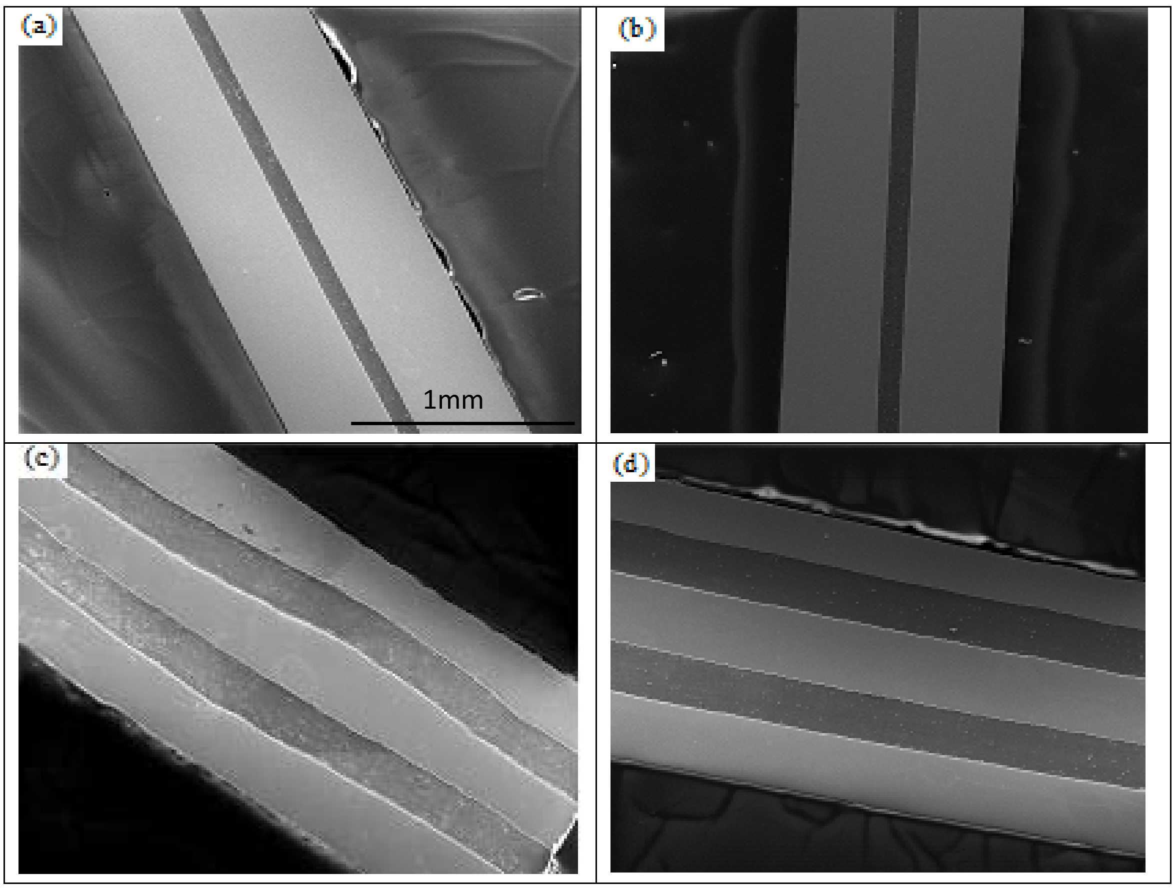
4. Summary of the most important results

The results show that titanium grains were heavily elongated along the rolling direction and just slightly elongated along the transverse direction; AZ31 magnesium alloy layers had equiaxed grains. There are smaller grains in the center of an AZ31 magnesium alloy layer than in the region close to the interfaces. The layer interfaces were observed under scanning electron microscope and the images show that the two types of materials were bonded at the interfaces. The tests show that the interface bonding strength is at least 26.3

MPa, which is a good strength comparing with the reported literature data for other metallic bonding interfaces. The specific results are described below.

- Production of multilayered samples: three types of multilayered samples were processed to have 3 layers, 5 layers, and 7 layers respectively.

- Microstructure characterization – layered structure: both optical microscope and scanning electron microscope were utilized to observe the microstructure of the samples. Three-layered samples have the titanium layer, AZ31 magnesium alloy layer, and titanium layer. Both five-layered and seven-layerd samples have the alternative titanium and AZ31 magnesium layers and the outermost layers are titanium. Figure 1 shows the images of each type of sample along both the rolling direction (RD) and the transverse direction (TD).



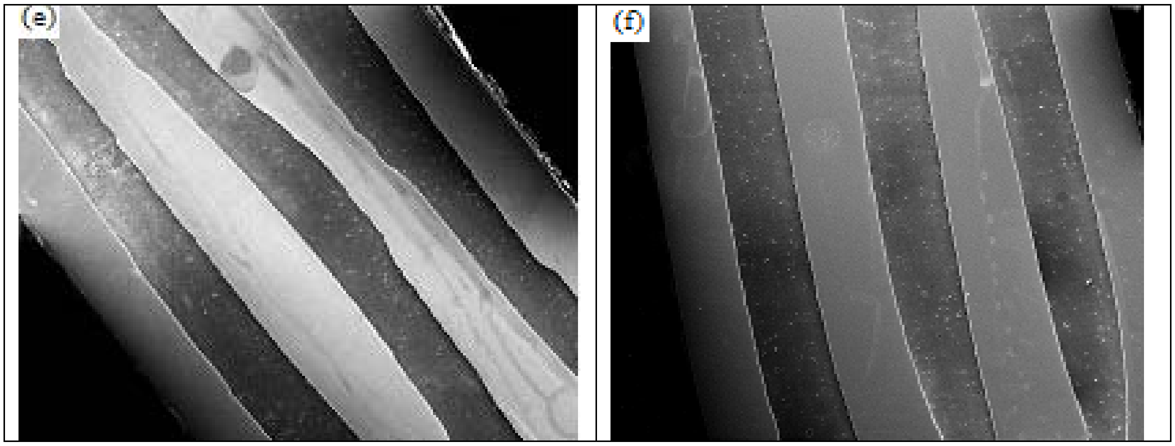


Figure 1. SEM images of Ti-AZ31 multilayered samples with 3 layers (a) RD, (b) TD; 5 layers (c) RD (d) TD; and 7 layers (e) RD (f) TD. (The images have the same micron bar.)

- Microstructure characterization – internal structure of individual layers: Figure 2 shows some representative images of titanium layer and AZ31 magnesium alloy layer. The grains of titanium obviously elongated at RD and slightly elongated at TD after hot rolling. The grains of AZ31 magnesium alloy were refined and equiaxed. The grains at the center of AZ31 magnesium layer were finer than the ones at the interface region.

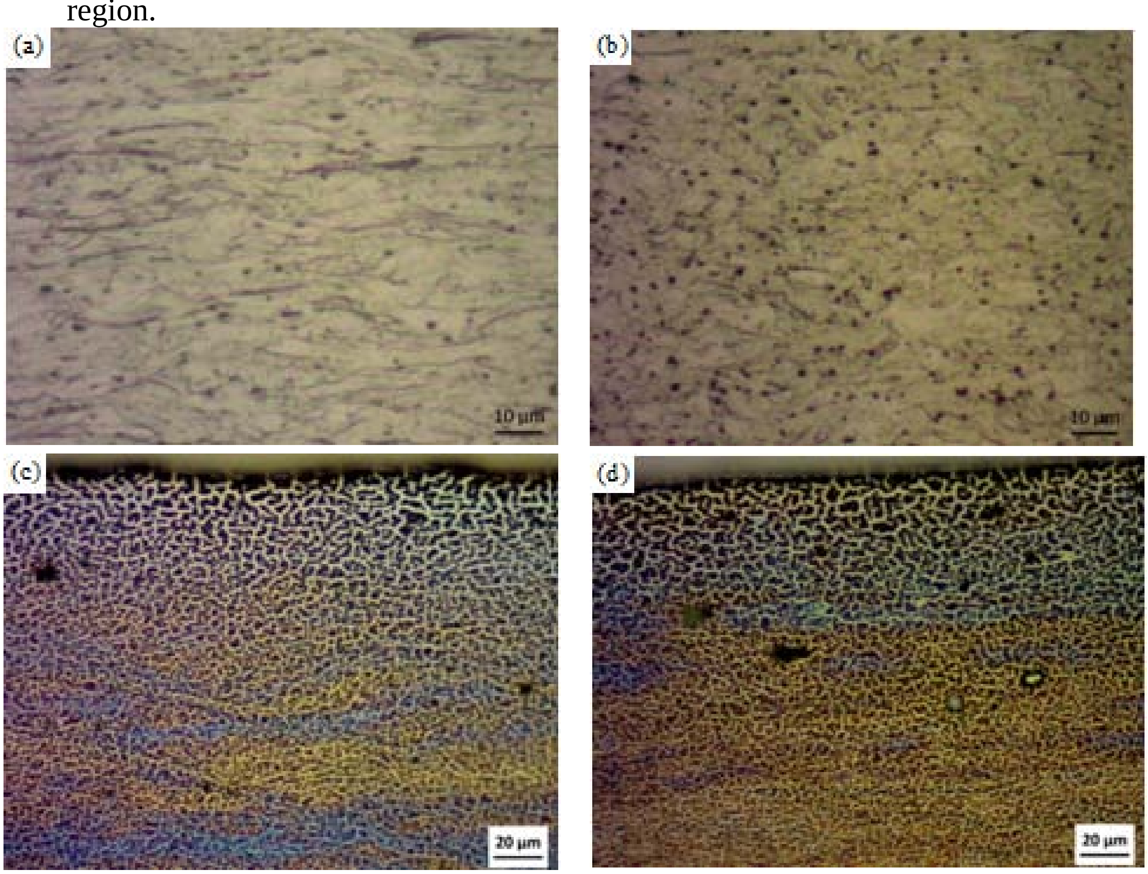


Figure 2. OM images of titanium layer in the 3 layered sample at (a) RD and (b) TD; OM images of AZ31 magnesium alloy layer in the 5 layered sample at (c) RD and (d) TD.

- Microstructure characterization – interfacial structure: Figure 3 shows some representative SEM images of the interfaces between titanium layer and AZ31 magnesium alloy layer. The two types of materials were bonded and the interfaces are sharp.

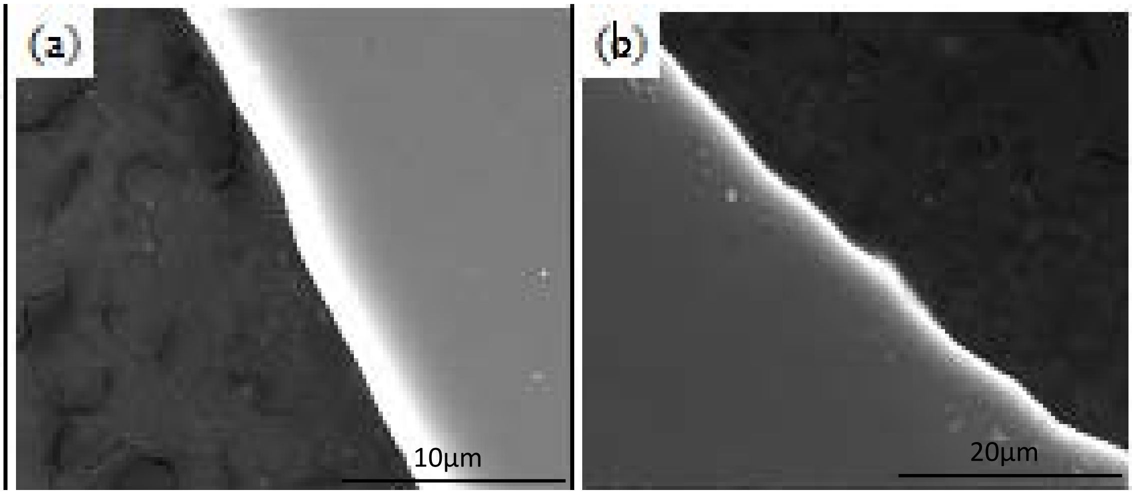


Figure 3. SEM images of interfaces for (a) the 3-layered material and (b) the 5-layered material.

- Bonding strength: It is a challenging task to obtain the direct data about the bonding strength of the interfaces. It was tried to glue the sample to two platens and then applied tensile loading to debond the samples. Due to the limit of the glue strength, the samples detached before being broken at about 26.3 MPa. It concludes that the bonding strength is at least 26.3 MPa. This was compared with other reported bonding strength in Figure 4 [10]. The strength of our samples is lower than those for aluminum/titanium (Al/Ti) and aluminum/niobium (Al/Nb), and is higher than those for aluminum/iron (Al/Fe) and cupper/titanium (Cu/Ti) [10]. It is comparable to the reported data for the samples in the literature.

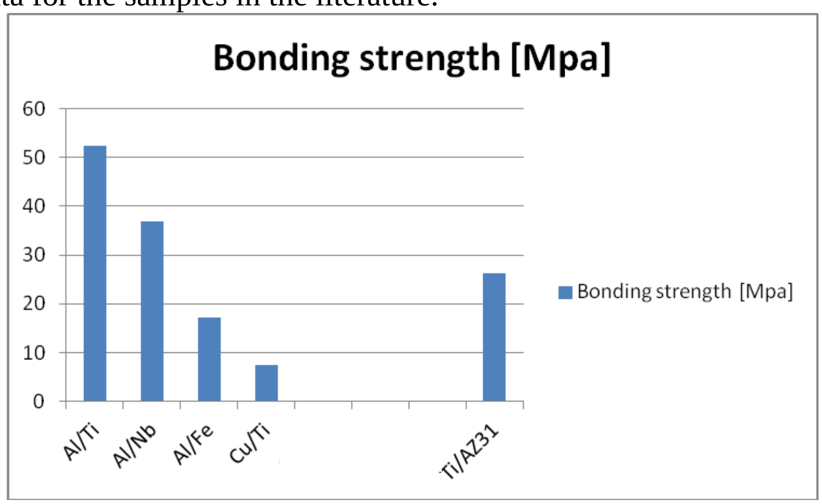


Figure 4. The comparison of different cold rolled bonded bimetal [10] with our samples.

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6. Appendixes

None

7. Other

One graduate student was supported to perform the project. Since this is a short term project, there is no graduate student graduated. The results are planning to be presented in a conference titled “the International Conference on Metallurgical Coatings and Thin Films” in April 2016.