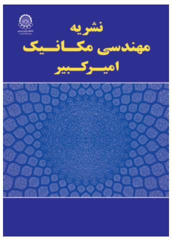

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 50(3) (2018) 153-156
DOI: 10.22060/mej.2017.12161.5273

Influence of Interface Morphology on the Bond Strength During the Reshaping Process of Al-Cu Bimetal Pipes

A. Tajyar[1], A. Masoumi[2*]

[1]Department of Industrial Design - Faculty of Architecture and Urban Design-Art university of Isfahan-Isfahan-Iran
[2]School of Mechanical Engineering, College of Engineering, University of Tehran, Tehran, Iran

ABSTRACT: With the increasing advances in various industries such as aerospace, chemical and fluid transfer, manufacturing of bimetal noncircular tubes as their frequent use is more than ever important. In the present study, the squaring process of aluminum-copper bimetal pipes produced by explosive welding, using rolling process was studied. The effect of interface morphology on the microstructure and strength of the bond interface during the reshaping process was investigated by an optical microscope and shear strength test. Moreover, the presence and distribution of the intermetallic compounds at the interface was investigated by the electron microscope and energy dispersive X-ray spectroscopy analysis. The results show that the wavy form of the interface and the continuity and thickness of the intermetallic compound layer which is formed at the interface of the initial round pipes have a major importance during the reshaping process and effect on the mechanical properties and interface quality of the finished square tubes. Bond strength of tubes with wavy form interface and minimal intermetallic compounds at their interface, have not changed significantly before and after the forming process but the bond strength decreases by increasing the thickness of intermetallic compound layer and the drop in bond strength during the forming process is more severe for the tubes with thicker intermetallic compounds layer at their interface.

Review History:

Received: 16 November 2016
Revised: 30 January 2017
Accepted: 16 April 2017
Available Online: 23 April 2017

Keywords:

Reshaping process
Square bimetal tube
Bond interface
Explosive welded circular pipe

1- Introduction

Due to recent advances in various industries such as liquid transportation, natural gas, and petroleum, chemical and heat exchangers, demand for non-circular tubular bimetallic products have been widely increased.

The bonding strength and formability of steel/aluminum clad tubes prepared by explosive bonding method were investigated in the next forming process by Guo et al. [1]. No separation after the cold extruding and hydroforming process showed that the clad tube had excellent bonding properties and could endure the second plastic deformation. Sun et al. [2] studied bonding characteristics of the explosive welded Fe/Al clad tube interface before and after the hydro-bulging process. It is found that the good-bonding interface of the Fe/Al clad tube plays a dominant role in the formation of the T-shape. Tajyar and Masoumi [3] investigated the effect of shape rolling process in different passes on the mechanical properties of Al/Cu bimetallic pipes. The experimental results showed that by increasing the amount of roll gap reduction in each pass, the microhardness of layers increases and the bond strength decreases. Chen and Ye in two studies examined the squaring process to shape a circular tube into a symmetric square clad tube by a three-dimensional incremental elastic-plastic finite-element method [4, 5]. The effects of various parameters on the occurrence of collapse in the squaring process were discussed and interpreted in a theoretical manner.

In the present study, experimental analysis of reshaping thick bimetallic circular pipes into square tubes has been performed. The influence of the interface morphology of initial two-layer circular pipe on the microstructure and bond strength of interface after the reshape rolling process was studied. To investigate this objective, the morphology of the interface before and after the shape rolling for various conditions was examined.

2- Materials and Methods

In this study, the thick bimetallic circular pipes which were produced by the explosive welding process reshaped into square tubes through four flat rolls. The samples were cold rolled at five passes with roll gap reduction of 2 mm for each pass. In order to study the morphology of the interface bonding and the evaluation of the effect of the subsequent rolling process, interfaces were analyzed through an Optical Microscope (OM). Moreover, the presence of the intermetallic compounds at the interface was investigated by the Electron Microscope (SEM) equipped with Energy Dispersive X-ray Spectroscopy (EDS). Moreover, the shear strength of the bonded joints was evaluated for the clad circular pipes and shape rolled tubes.

3- Results and Discussion

3- 1- Microstructural observation

During the subsequent forming process on two-layer pipes, failures may occur due to non-uniform distribution of stresses in the bonding zone and intensification of metallurgical defects that can be created in the welding process. A network of cracks may be formed at the interface of the final sample during the reshaping process. The presence of this network of micro-cracks may cause separation and fracture at the interface. Fig. 1 (a) shows an image of the interface of the explosive-welded bimetal circular pipe. As can be observed, the morphology of the joint was characterized by thick and continuous intermetallic layer with initial vertical

Corresponding author, E-mail: amasomi@ut.ac.ir

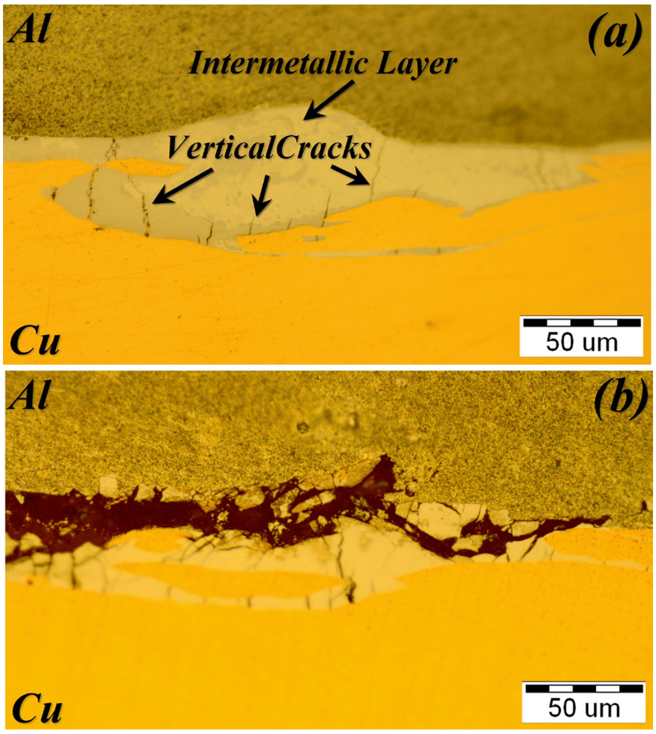

Fig. 1. Cross-section optical image of Al/Cu interface with thick and continuous intermetallic layer (a) after explosive welding process (b) after the last stage of shape rolling process.

micro cracks. Fig. 1 (b) shows an image of the interface of the aluminum and copper tube after the last stage of shape rolling process. It is observed that the separation occurred at the interface of the bimetallic tube. During the shape rolling, intensive crack propagation in the microstructure of the bonding zone is obvious and as a result, breaking occurs at the last stage of forming process. The presence of initial cracks in thick and continuous intermetallic layer accelerates the nucleation and propagation of micro-cracks during the shape rolling and consequently increasing the number of cracks can cause separation at the interface.

Fig.2 (a) shows the morphology of the interface of the Al/Cu pipe which was characterized by regular wavy structure and minimum intermetallic compounds. Fig. 2 (b) shows an image of the interface of the Al/Cu tube after the last stage of shape rolling process. It can be seen that no significant microstructural changes were identified and the wavy pattern at the Al/Cu interface is kept. On the other hand, the resistance of the wavy interface is enough during the shape rolling and it was not damaged. Also, no evidence was found that the intermetallic inclusion was affected by the loading during the shape rolling process, despite the expectation that brittle intermetallic compounds should be more susceptible to cracking. The number of intermetallic compounds have no adverse effects on the interface during the rolling process.

3- 2- Shear strength

The results of the shear strength tests of Al/Cu joints before and after shape rolling process revealed that the shear strength decreases when the intermetallic layer thickness increases and drop in the joint shear strength is more intensified after the shape rolling process for the samples with a thicker intermetallic layer. But the results for the interface of the sample with the wavy structure and minimum intermetallic

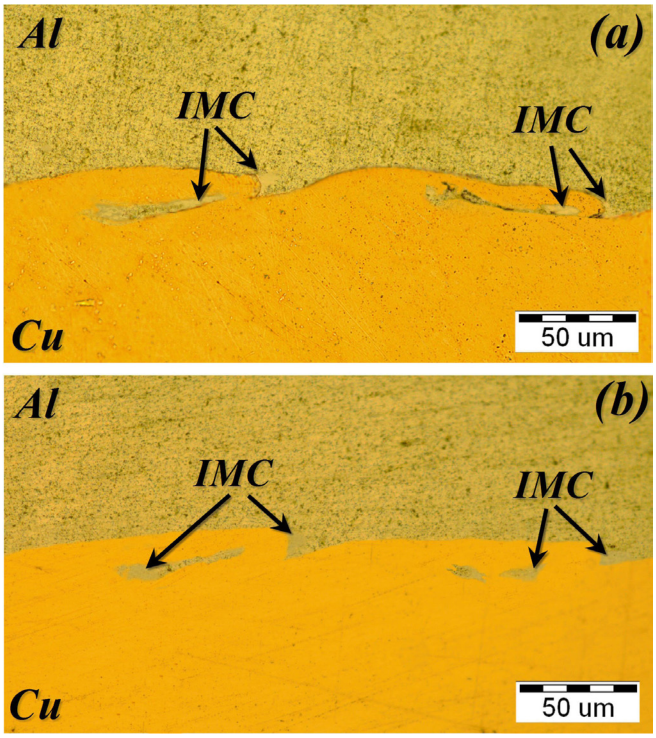

Fig. 2. Cross-section optical image of Al/Cu interface with wavy structure and minimum intermetallic compounds (a) after explosive welding process (b) after the last stage of shape rolling process.

compounds indicate that there are no significant changes in the shear bond strength of the interface before and after shape rolling and the fractures have occurred parallel to the weld line and in the aluminum layer. It indicates that the joint shear strength after rolling process is still higher than the strength of the aluminum.

4- Conclusion

In this study, based on evaluating the properties of the interface for different conditions before and after the reshaping process, the following results can be concluded:

- The continuity of intermetallic compound layer and initial vertical cracks are the effective factors on the bond strength of the interface during the reshaping process.
- In specimens which have the wave-shaped interface with intermetallic compounds, the wave pattern is maintained during the next forming process, but the area includes the intermetallic compounds which are affected during the reshaping process. By increasing the amount of these compounds at the interface, the amount of micro-cracking at the interface is further expanded during the forming process.
- In the case of wavy form interface and minimum intermetallic compounds, the resistance of the wavy interface is enough and is not damaged. The waves are as a barrier during the reshaping process and the intermetallic compounds have no destructive effect on the interface during the reshaping process.
- By increasing the thickness of the intermetallic layer at the interface, shear strength drop is more severe during the forming process. But for specimens which have the regularly wave-shaped interface and minimum

intermetallic compounds, there is no significant reduction in shear bond strength after reshaping process and separation occurs in the aluminum layer and parallel to the interface. These results show that the bond strength of the two-layer tube after reshaping process is still higher than the strength of the aluminum.

References

[1] X. Guo, H. Wang, Z. Liu, L. Wang, F. Ma, J. Tao, Interface and performance of CLAM steel/aluminum clad tube prepared by explosive bonding method, *The International Journal of Advanced Manufacturing Technology*, 82(1-4) (2016) 543-548.

[2] X.-J. Sun, T. Jie, X.-Z. Guo, Bonding properties of interface in Fe/Al clad tube prepared by explosive welding, *Transactions of Nonferrous Metals Society of China*, 21(10) (2011) 2175-2180.

[3] A. Tajyar, A. Masoumi, Experimental analysis of bonding strength in shape rolling of Al–Cu bimetallic circular pipes into square tubes, Proceedings of the Institution of Mechanical Engineers, *Part C: Journal of Mechanical Engineering Science*, 231(22) (2017) 4087-4098.

[4] T.C. Chen, J.M. Ye, Finite-element analysis of the double lateral compression of clad tube into a Symmetric Square-Tube, in: Advanced Materials Research, *Trans Tech Publ*, 337(2011), 332-335.

[5] T.-C. Chen, J.-M. Ye, Finite-Element Analysis of the Lateral Compression of Clad Tube between V-Shaped Dies, Journal of the Chinese Society of Mechanical Engineers,34(4), (2013)), 331-340.

Please cite this article using:

A. Tajyar, A. Masoumi, Influence of Interface Morphology on the Bond Strength During the Reshaping Process of Al-Cu Bimetal Pipes, *Amirkabir J. Mech. Eng.*, 50(3) (2018) 467-478.

DOI: 10.22060/mej.2017.12161.5273