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Original Article

Mechanical characteristics of dissimilar alloy friction welded joint

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Abstract

Shape Memory Alloys (SMAs) offer specific adaptability to complex shaped structural parts. In this study, two dissimilar shape memory alloys are welded by friction welding and put through mechanical testing to find the best results for those alloys that are welded together. On finding the best match of the alloys, we can compare the results with the alloy's base properties. The shape memory alloy is welded with another shape memory alloy by solid-state welding that enhances the mechanical properties like hardness, tensile strength, flexibility, and improves its properties additionally in heat resistance and vibration resistance cost-efficiently. Friction welding was done using different parameters, and tensile testing was conducted for all the welded specimens. Metallurgical study was conducted for the highest tensile strength welded joint to produce a legitimate weldment that is capable of enduring sustained heat and vibration from other metals and gives a sustainable bond between the alloys, so they can be used in a large number of applications reducing the cost, creating a shape memory alloy weldment with another base alloy and to improve their characteristics without any loss of desired properties.

Keywords: Cu based shape memory alloy, Fe based shape memory alloy, friction welding, mechanical study, metallurgical study

1. Introduction

To find the mechanical characteristics and the metallurgical properties of the shape memory alloys that are joined using friction welding with dissimilar metals or alloys, for numerous potential applications like in medical, automobile, dental, aerospace, and other fields. The main idea of this project was to identify the best alloy from a selection, and study the metallurgical characteristics. This project aims to provide a cost-efficient and effective way of using shape memory alloys in various fields. One of the best ways to join two dissimilar alloys of varying composition is by Tig welding (Lü, Yang, & Dong, 2013). When welded with other metals, the shape memory alloy of iron has greater strength and a reduction of stress (Ghowsi, Sahoo, & Ashwin Kumar, 2020). Casting, powder metallurgy, and continuous solidification are all methods for producing copper-based shape memory alloys (Agrawal, & Dube, 2018). Joining copper-based and iron-based shape memory alloys is performed by friction welding since the creation of intermetallic layers is greatly reduced, improving the strength of joint between dissimilar metals.

2. Methodology

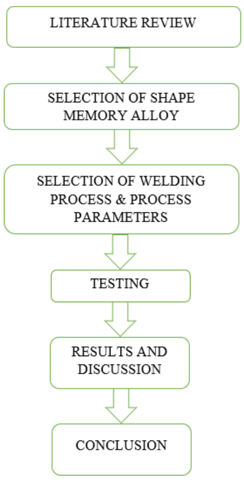

Figure 1. Methodology Flowchart

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3. Experimental Procedure

3.1 Selection of SMA

The SMAs selected for the experiments were Copper Nickel Aluminium Ferrous (Cu Ni-Al Fe) and Ferrous Manganese Silicon Chromium Nickel (Fe Mn Si Cr Ni) (Abuzaid *et al*., 2019). The reason for selecting these two was that they are suitable shape memory alloys with the required mechanical properties and metallurgical composition, while also being cost-efficient.

The average tensile strength of Cu-based alloy is 700Mpa, while that of the Fe-based alloy is 500Mpa

The chemical composition of Cu-based alloy was Al-10.5%, Fe-4.2%, Ni-3.1% and remaining part is copper, while that of Fe-based alloy was Mn-15%, Si-5%, Cr-9%, Ni-5% with the remainder being iron.

Dimensions of the alloy exemplars

Material	Copper based alloy (Cu Ni-Al Fe)
Size	150*20 mm
Shape	Round bars
Quantity	6
Condition	Super elastic and shape memory effective

Material	Iron based alloy (Fe Mn Si Cr Ni)
Size	150*8 mm
Shape	Round bars
Quantity	6
Condition	Super elastic and shape memory effective

Figure 2. Copper based SMA (Cu Ni-Al Fe)

Figure 3. Iron based SMA (Fe Mn Si Cr Ni)

Table 1. Parameters tested in friction welding

Parameter	Specimen 1	Specimen 2	Specimen 3
Friction pressure (MPa)	22	22	22
Upset pressure (MPa)	65	65	65
Burn-off length (mm)	1	1	1
Rotational speed (rpm)	500	1000	1500

3.2 Preparations and friction welding of dissimilar SMAs

In friction welding the workpieces are joined together by using the heat created by friction between them. By using the friction between the metals and the workpiece, they tend to soften and mix with the workpiece, and later on, when cooling down the workpiece, they will become hard due to the bonds created between the metals. Friction welding is used because it is the most suitable welding method for the selected SMAs, which are copper based and iron based. Using this type of welding will result in a higher quality weld from a very short processing. Tubes and shafts are welded using this type of welding. There are various parameters to be considered for the required results, such as friction pressure, upset pressure, burn-off length, and rotational speed.

3.3 Welding parameters used

The friction welding process was done using the parameters in Table 1.

The process parameters have been decided with the help of a reference cited [5] that discusses this welding method and its parameters. The dissimilar SMAs were welded with the mentioned parameters and required conditions.

3.4 Testing

3.4.1 Mechanical testing

Mechanical testing is used to determine mechanical properties or characteristics of the materials, like toughness, hardness, strength, brittleness, and ductility.

3.4.2 Tensile testing

The six friction welded joints were subjected to tensile testing. The tensile test holds the workpiece between grips, fixing one end and applying an external load to the material. The material is measured for its dimensions and cross-sectional area. Using this type of testing, we can find out the tensile modulus possessed by the material, and more generally the stress response to elongational strain. The specimens fail at different stages of testing, depending upon the friction welding parameters. Thus, different tensile strengths for the weld joints are obtained as shown in Table 2.

Figures 4 and 5 show the welded joints after conducting the tensile strength test. The fracture location in specimens was at the welded zone, and the nature of fracture was brittle. The tests were conducted for two sets (6 pieces) for all specimen types, and the nature of fracture and fracture position were the same in all cases.

Table 2. Tensile test results

Specimen number		Size (mm)	Area (mm^2)	Tensile load (KN)	Tensile Strength (MPa)	Mean value (MPa)	Fracture position	Nature of fracture
Specimen 1	Trail 1	9.91	77.13	22.19	287.66	289.91	Broken at weld	Brittle
	Trail 2	9.92	77.23	22.36	292.16			
Specimen 2	Trail 1	9.92	77.29	27.94	361.47	352.07	Broken at weld	Brittle
	Trail 2	9.93	77.54	26.94	342.68			
Specimen 3	Trail 1	9.91	78.23	27.03	345.49	343.65	Broken at weld	Brittle

Figure 4. Welded joints after testing (Set-1)

Figure 5. Welded joints after testing (Set-2)

Figure 6. Welded joints before testing

3.4.3 Metallurgical study

This was used to assess the characteristics of the workpiece, such as the physical and chemical behaviours of the material and the reaction of joining the metal with other dissimilar metals. Figure 7 shows the zone used for analysing the microstructure of intermetallic region and the zone where breakage happened while testing tensile strength. The metallurgical study is divided into chemical and physical metallurgy.

3.4.4. Spectroscopy

This was used to determine the elemental components in the samples of solid metals used. Spectroscopy can provide both high accuracy and precision, and rods, wires, or plates can be used in this type of study.

3.5 Results of testing

The shape memory alloy, which is welded, has been put through mechanical testing, and the results and the final data have been gathered.

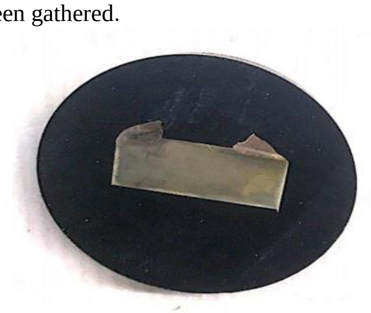

Figure 7. Microstructures of studied specimens

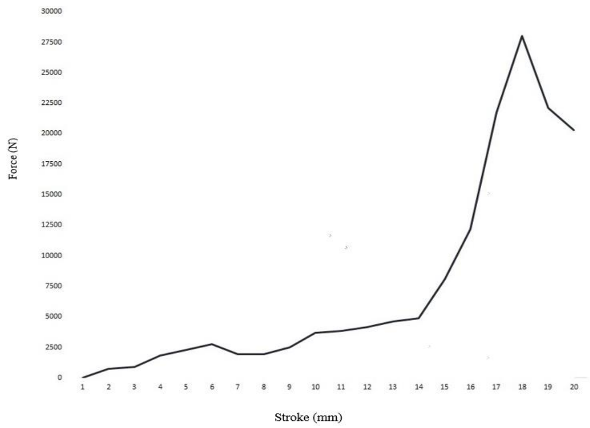

Figure 8. Tensile strain graph for specimen 2 Trail 1

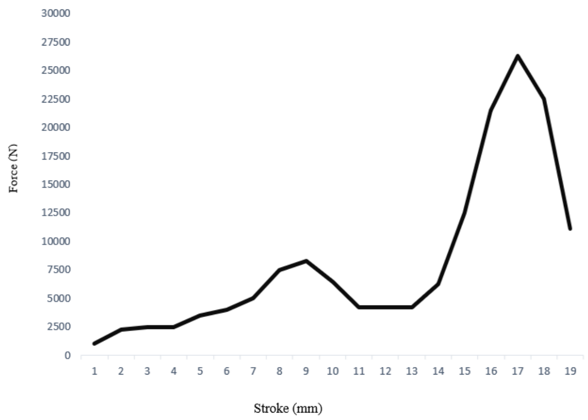

Figure 9. Tensile strain graph for specimen 2 Trail 2

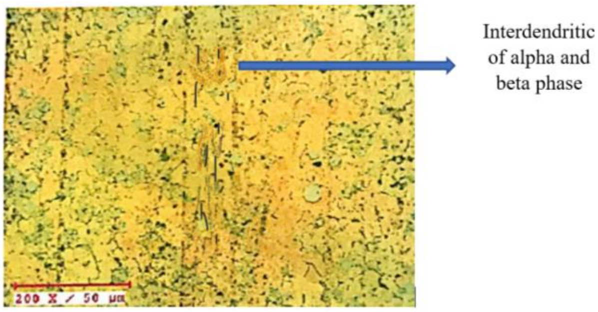

Figure 10. Microstructure image of SMAs

In microstructural study a metallurgical microscope (Dewinter tech) and potassium dichromate as etchant were used. The microstructure at the welded area shows interdendritic material of iron and silicon-based intermetallic components. In this matrix, some Al particles were also observed. These intermetallic compounds play a vital role in reducing shape memory effects at the welded zone.

4. Applications

The basic application of the experimental procedure is to find shape memory alloys and the best parameters for friction welded joints to withstand high pressures, heat, and loads to make a shaft that has high resistance to heat, thus making it resistant so it doesn't require an external cooling system.

Many shape memory alloys can perform this in cast state but not as efficiently as a combination of elements when friction welded, providing superior strength and heat resistance required for many structural purposes such as in medical, industrial, automobile, aerospace, and golf club applications. They are used in fields where motions, flexibility, and elasticity are at critical levels.

5. Results

The outcomes from testing the mechanical properties of the welded rods of copper based and iron based shape memory alloys using friction welding are summarized in Table 3.

After testing, all the specimens were welded at a fixed friction pressure of 22 MPa and the upset pressure was also fixed at 65 MPa, with the burn-off length set at 1 mm. The specimens were welded at different speeds of rotation, namely at 500 rpm, 1000 rpm, and 1500 rpm, and the first and third specimens had tensile strengths comparatively less than the second specimen.

In the first specimen, the required temperature was not met, whereas in the third specimen the temperature was high. The intermetallic component that created was high and reduced the tensile strength when compared with the other two specimens. The second case gave the highest tensile strength. It is observed that the test pieces were broken at the weld during testing. The welded zone was brittle due to the creation of Al-Fe-Si-based intermetallic components. Because of this intermetallic component's creation in the shape memory alloy, the zone of weldment was weak.

Table 3. The final tensile strengths

Specimen number	Friction pressure (MPa)	Upset pressure (MPa)	Rotational speed (rpm)	Mean Tensile strength
Specimen 1	22	65	500	289.91 MPa
Specimen 2	22	65	1000	352.07 MPa
Specimen 3	22	65	1500	343.65 MPa

6. Conclusions

The copper based (Cu-Ni-Al-Fe) and iron based (Fe-Mn-Si-Cr-Ni) shape memory alloys were used in joining dissimilar alloys by welding.

Friction welding was chosen due to its characteristics. In prior work, it is well-known that solid-state welding is best suited for joining shape memory alloys.

It is observed that specimen 2 prepared with a rotational speed of 1000 rpm, attained the highest tensile strength among the cases tested. The tensile strengths were determined for two sets, to provide conclusive evidence.

The creation of Al-Fe-Si-based intermetallic components reduced the tensile strength of the specimens. Due to the intermetallic layer, all welded joins were broken at the welded area with brittle failure, while also the shape memory effects at joint suffered losses. However, this effect can be reduced by using chemical treatments before welding the alloys, which can also increase the tensile strength as the intermetallic component formation is reduced, along with reducing brittleness of the joint.

The best-welded joint was subjected to a metallurgical study by spectroscopy study microstructural assessment.

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