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Gas Metal Arc Welding (GMAW) of Pseudoelastic Nickel-Titanium Shape Memory Alloys

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Abstract

Nickel-Titanium alloys are widely used shape memory alloys due to its high strain recovery and thermomechanical stability. But the low formability of these alloys, obstruct the fabrication into required geometrical structures as demand for applications in earthquake-resistant structures. So, the welding becomes inevitable for the fabrication of NiTi alloys. In this study, the pseudoelastic NiTi alloy was welded using GMAW process. X-ray diffractometric analysis was used to study the phases in the base metal and the weld. The effect of welding on shape memory behavior was analyzed using differential scanning calorimetry (DSC) technique. The shape memory behavioral change with respect to the phases has been analyzed. The weld showed poor shape memory behavior due to the contamination caused by the welding. The suitability of GMAW process for welding the NiTi alloy is also discussed.

Keywords:Shape memory alloy, Nickel Titanium, gas metal arc welding, differential scanning calorimetry

1. INTRODUCTION

Shape memory alloys (SMA) are a class of smart materials which has a unique capability of recovering shape or strain at particular characteristic temperature. The shape recovery is governed by diffusion less solid state transformation between two phases viz. austenite (high-temperature phase) and martensite (low-temperature phase). Due to distinct shape memory effect, superelasticity and biocompatibility, it has been applied in diverse engineering fields such as aerospace, civil, mechanical and biomedical[1,2]. The widely used NiTi SMA alloy has poor formability and the fabrication of required complex structures is an issue. To solve this issue, many researchers have attempted welding of NiTi SMA using various techniques namely tungsten inert gas welding, plasma welding, brazing, laser welding, friction stir welding and electron beam welding[3–7].

In the last two decades, the NiTi SMA has been applied to many civil structures for seismic applications [8]. The welding techniques like laser welding, electron beam welding and friction stir welding cannot be operated on the building construction or industrial fields as per the need.GMAWwill serve the purpose of welding NiTi to NiTi or to other braced structures in the work field itself at low cost. GMAW is a fusion welding technique which uses a consumable wire electrode and establishes an electric arc between the wire electrode and the work material in an inert gas shielded atmosphere. The arc will melt the edges along with the wire electrode and on solidification weld will be formed. One of the greatest advantages over other welding technique is that GMAW can be performed at all positions.In this work, an attempt has been made to weld NiTi sheet using GMAW process. The presence of crystal phases and phase transformational behavior of the base metal and the weld has been studied in detail.

2. EXPERIMENTAL SETUP

The NiTi SMA sheet (SE508) of thickness 1.2 mmin straight annealed condition supplied by confluent medical was used for welding. The nominal chemical composition is 55.8 weight % Nickel having austenite phase at room temperature. The process parameters used for welding is shown in Table 1. The welding was performed using ESAB GMAW machine. The superelastic NiTi wire of 1.2 mm (SE508-55.8 wt% Nickel) diameter was used as the wire electrode. The welding surface was mechanically polished to remove the oxide and other impurities adhering to the surface. The welding was performed at butt configuration with a gap of 1mm between the plates.Initially,trail experiments were conducted to optimize the process parameters. The parameters used for welding is listed in Table 1.

The phase analysis was carried out using Rigaku: smart lab automated multipurpose X-ray diffractometer. The shape memory behavior was studied with DSC technique using Netzsch-DSC214 Polyma machine at a heating/cooling rate of 10^{o}C/min with constant flow nitrogen atmosphere. For DSC experiments, samples of weight20 mg was cut from the base metal, weld fusion zone (FZ) and weld heat affected zone ((HAZ) to find the change in phase transformation behavior from fusion zone to the base metal.

Table 1
Process parameters used for welding

S.No	Parameters	Value
1.	Voltage (V)	12.4
2.	Feed rate(cm)	2.5
3.	Shielding gas - Argon (LPM)	12
4.	Wire electrode diameter(cm)	0.12

3. RESULTS AND DISCUSSION

The top surface of the welded sheet is shown in the Fig.1. Oxidation was noticed in some regions of the weld surface in spite of shielding gas used during welding. This could be possibly due to high affinity of NiTi molten pool to the atmospheric elements. The surface defects such as porosity, voids and spatter was not found in the weld surface.

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`Fig. 1.NiTi SMA welded using GMAW

The Fig.2 shows the XRD patterns of the base metal and the weld at room temperature. The base metal and the weld has austenite phase (B2-cubic). The weld has the base metal crystal phases without the presence of any intermetallic compounds such as $NiTi_2$ and $TiNi_3$.

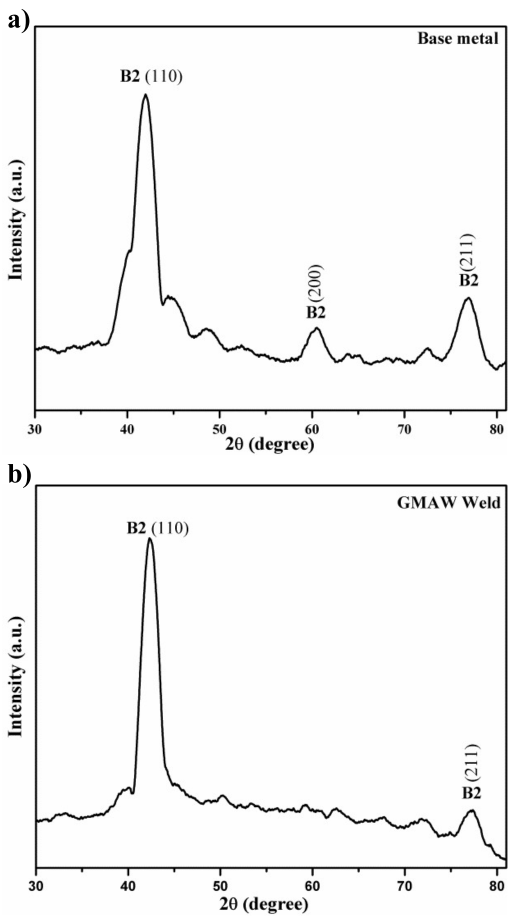
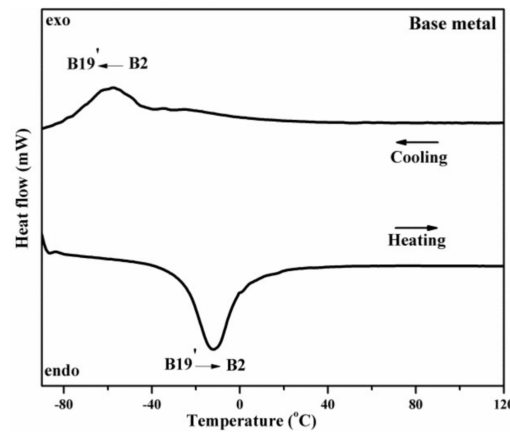
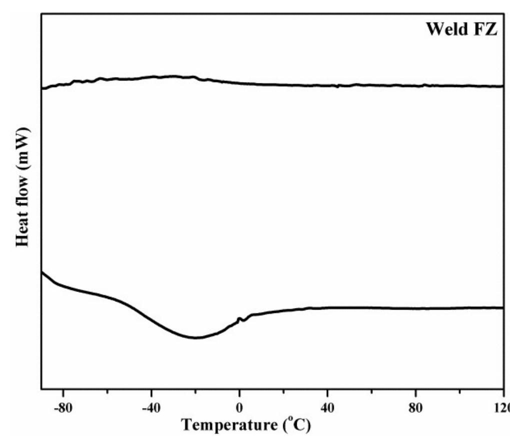


Fig.2.XRD patterns of a) base metal and b) GMAW weld

The fusion zone experiences complete melting, mixing of wire electrode with the sheet edges and then solidify to form the weld joint. The heat affected zone is the region which does not experience melting and the temperature will be below the solidus temperature. The Fig.3 shows the phase transformational behavior of the base metal, weld FZ and weld HAZ. On heating (endothermic), the reverse transformation from martensite to austenite phase (B19'→B2) takes place.On cooling (exothermic), the forward transformation from austenite to martensite phase (B2→B19') takes place. The base metal shows phase transformation in both endothermic and endothermic cycles. The phase transformation temperatures of the base metal and weld FZ is given in the Table 2. The weld FZ has shown proper phase transformation during endothermic cycle while the forward transformation was comparably poor. The phase transformation behavior of weld HAZ on both heating and cooling cycles has lost significantly due to welding and the peaks were not clearly evident. This loss in shape memory behavior could be attributed due to inclusion of contaminants and more detailed analysis has to be conducted to validate the reason.



a)



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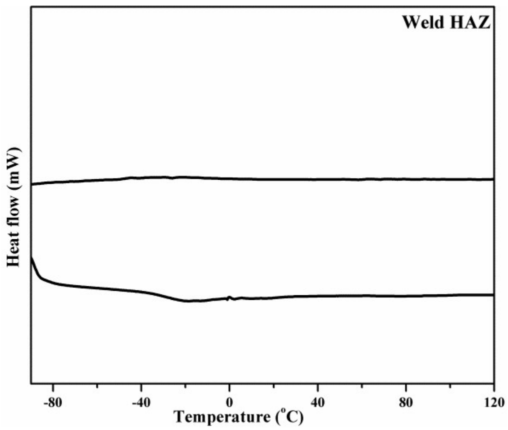

c)

Fig.3.Phase transformational behavior of the a) base metal, b) weld fusion zone and c) weld HAZ.

Table 2

Phase transformation temperatures of the base metal and the weld HAZ

	A_s	A_f	M_s	M_f
Base metal	-26	5	-43	-77
Weld FZ	-55	8	-	-

The hysteresis due to elastic energy (A_f - A_s) is 31°C for base metal and 63°C for weld FZ. The hysteresis has increased twice due to welding. The change in transformation behavior can be due to change in chemical compositions in the weld as even a mild change (0.1 at % of Ni) will have significant effect. The other factors such asdifference in dislocation density, grain surface and grain edge per unit volume and residual stress may also have influenced the phase transformation behavior[3].

4. CONCLUSIONS

- The NiTi superelastic SMA has been welded using GMAW process.
- The weld was formed without the precipitation of any intermetallic compounds.
- The weld FZ has retained the phase transformation behavior in the reverse transformation and the hysteresis was found to be higher than the base metal.
- The weld HAZ has lost the shape memory behavior due to the welding.

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