

## Preface

AISI 409L ferritic stainless steel is a widely used engineering material owing to its low cost in spite of its corrosion resistance properties. It possessed high thermal conductivity and lower thermal expansion coefficient compared to the austenitic stainless steel. Although its corrosion resistance is inferior to austenitic stainless steel, it better resists stress corrosion cracking in a chloride environment. Its oxidation resistance at high temperature is also higher; therefore, it is widely used in automotive exhaust systems such as mufflers, tail pipe, catalytic converter and exhaust manifold.

Ferritic stainless steels, including AISI 409L, are generally welded using gas metal arc welding process. However, grain coarsening of the weld metal zone and the heat affected zone is a major drawback in the welding of ferritic stainless steel. The grain coarsening can be eliminated to some extent using filler wire of austenitic grades such as austenitic grades ER304L, ER308L and ER316L, but the heat affected zone still possesses coarser grains.

Friction stir processing is a new technique based on friction stir welding that can be used to refine the grains of a material.

In this study, efforts have been made to initially optimize the process parameters to produce gas metal arc welding butt welds in plates of AISI 409L using ER304L (austenitic grade) filler material. Butt welds were produced on plates of 3 mm thickness using different heat input conditions by varying the welding current, welding voltage and welding speed. Other process parameters like root gap, shielding gas flow rate and stand-off distance were kept constant. The weldments were tested for the hardness, tensile strength, residual stress and Charpy impact toughness. The effect of heat input on the percentage dilution, microstructure, hardness, tensile strength, residual stress and Charpy impact toughness of the welded plates have been investigated.

The microstructure consisted of finer grains in the weld metal zone and coarser grains in heat affected zone. The applicability of the magnetic Barkhausen noise analysis and magnetic hysteresis loop has been demonstrated for both the welded plate as well as the processed plate. The testing was performed at each region of the welded plate, i.e. weld metal zone and heat affected zone, and processed region of the processed plate at different combination of magnetic Barkhausen noise process parameters. From this characterisation technique, it was found that the grain size affects the response parameters of the magnetic Barkhausen noise as well as the magnetic hysteresis loop.

The weldments with the best combination of mechanical properties obtained at optimized process parameters (sample S7) have been refined by using friction stir processing. The weld material and the heat affected zone on both sides were processed in a single pass. Friction stir processing has been carried out in such a way that the processing thickness was approximately half of the thickness of the welded plates. The friction stir processing tool material, tool geometry, and tool tilt angle to be used during friction stir processing were selected using extensive trial runs such that defects were prevented from occurring. The range of rotational speed and processing speed was found for the two different values of shoulder diameters. These process parameters (shoulder diameter, rotational speed and processing speed) were varied in a range of parametric window to perform the friction stir processing of the welded plate. The location of the friction stir processing tool has been kept above the centre of the weld metal zone such that the heat affected zone on both sides can be processed.

After performing friction stir processing on the welded plate, the plates were characterized to assess the mechanical and metallurgical properties. The processed region in the weld metal and the heat affected zone, both, consisted of refined grains of 3.0 microns and ferrite phases along with the austenite and martensite phases. The

average grain size of the processed region decreased on an average from 164.0 micron of heat affected zone to 3.0 micron after friction stir processing.

The average hardness of the processed region was also found more than the other regions, which imply that the hardness of the heat affected zone of the welded plate has also been improved. On performing transverse tensile testing of the processed plates, all tensile specimens have been fractured in the base metal zone, reflecting the improvement in the strength of the heat affected zone of the welded plate.

The effect of shoulder diameter and ratio of rotational speed to the processing speed has also been studied. It was found that for a given shoulder diameter, on increasing the ratio of rotational speed to the processing speed, the grain size of the processed region and thermo mechanically affected zone is decreasing, whereas the grain size of the heat affected zone (friction stir processing) are increasing. For a given set of process parameters, it was found that friction stir processing tool with a higher shoulder diameter produced coarser grains in all regions of the processed plate than the smaller diameter.

Similarly, the effect of shoulder diameters and the ratio of rotational speed to the processing speed on the hardness of different regions were also analysed. These variations were opposite to the variation as observed in the case of grain size.

The longitudinal residual stresses were also measured at different locations in each region of the welded plate and processed plate. In the case of the welded plate, compressive residual stresses have been found in the heat affected zone, while tensile residual stresses have been found in the base metal zone as well as weld metal zone. In the case of the processed plate, the base metal zone was under the tensile residual stress, and the processed region was under the compressive residual stress whose magnitude is more than the compressive residual stress exists in the welded plate as well as the area of the plate under compressive residual stress is also more than the case of the welded

plate. Therefore, the tensile residual stress of the weld metal zone was completely removed upon carrying out friction stir processing and get converted into the compressive residual stress.

Also, the micromagnetic analysis (magnetic Barkhausen noise and magnetic hysteresis loop) of the processed region of sample A has been carried out at magnetic field intensity of 800 Oe and magnetising frequency of 0.05 Hz. The obtained values of response parameters for different regions of the welded plate S7 and processed region of sample A have been compared to see the effect of friction stir processing on the micromagnetic response.

From the obtained results, it was concluded that friction stir processing might be used to refine the coarser grains of the heat affected zone, which in turn increases the strength of the heat affected zone. Thus the problems associated with the grain coarsening of the heat affected zone obtained in the gas metal arc welding of the ferritic stainless steel can be removed by using friction stir processing.