Effect of Gas Metal Arc Welding Parameters on the Behaviour of Heat Affected Zone of 316L SS and A572 gr. 50 steel

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By

Manish Deo

Department of Mechanical Engineering
Indian Institute of Technology
(Banaras Hindu University)
Varanasi-221005

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Chapter 5

Summary and Conclusions

This chapter summarizes the findings of the present investigation together with concluding remarks and the scope for future work.

5. Summary and Conclusions

5.1 Summary of thesis

This work was aimed at fabricating A572 gr. 50 and 316L SS steels under shielding gas environment of Ar+CO_2 by gas metal arc welding. For further optimization and enhancement of the performance of the weld joint, the Design of experiments using Taguchi's approach was used. Heat affected zone properties were analyzed for their contribution to the joint's mechanical properties through ANOVA and mechanical tests. The fabricated joints at different levels according to L_{16} orthogonal array were characterized for microstructural and mechanical properties in a comparative manner. The present investigation is divided into five chapters covering aspects described above:

i. In the first chapter, the Introduction of the arc welding process and factors responsible for controlling heat affected zone and its properties were briefly discussed. Types of welding processes, areas of application and associated defects of weld joints of A572 and stainless steel were addressed. DOE as a tool for optimization and factors responsible for degradation of weld properties due to weld thermal-cycle was also introduced.

ii. The second chapter presents a critical literature review on Gas Metal Arc Welding, modes of metal transfer, sub-zones of the heat affected zone, various phases formed in the microstructure and their contribution to the welded joint's properties. Welding variables and their contribution to heat affected zone and various optimization techniques were reviewed. Also, the variation of microstructural and mechanical behaviour was reviewed in detail.

iii. In the third chapter, materials used for the present investigation and experimental procedure under pre-mixed shielding gas of Ar+CO_2 via GMAW welding was discussed. The experimental details and selected parameters for single-pass welding, along with parameters that need to be controlled for optimum mechanical properties, are also included. The characterization details followed for the present study, such as macrostructure, microstructure, hardness and tensile properties have been discussed in detail.

iv. The fourth chapter presents a detailed discussion of macrostructural analysis, microstructural evaluation, microhardness survey and fracture morphology of A572 gr. 50 and 316L SS steels welded at variable current, gas flow rate and weld speeds. Characteristics like depth and area of penetration were studied, and DOE using Taguchi's approach, was used to find the optimum parameters and their contribution. The micrograph obtained by optical and scanning electron microscope revealed that single-pass weld microstructure had solidification-induced dendritic structure. The 316L SS welds depicted δ-ferrite morphology. The grain structure was heterogeneous in nature, and coarse grains were found near the fusion line. Heat affected zone showed different zones as WZ, CGHAZ, FGHAZ, ICHAZ, tempered zone and unaffected base material, moving away from the weld centre respectively for A572 gr. 50. Moreover, the HAZ grain size was remarkably increased by the grain growth mechanism and decreases with decreasing heat input. Decreased grain size leads to an increase in strength and ductility. Modifying welding process parameters can help to control heat input and optimize the joint properties. However, it was observed that low welding speed caused porosity, partial penetration, and excessive reinforcement. High speeds caused underfill and lack of fusion defects. Shielding gas mixture of Ar+CO_2 increased stability and penetration in single pass weld for 316L SS. From the present investigation, significant variations in bead morphology and microstructure can be seen under identical heat inputs. Optimum parameters for higher strength, low heat input and uniformity in grain size in HAZ can be achieved

v. Finally, in the fifth chapter, the present investigation's summary, concluding remarks and scope for future work have been presented.

Highlights

i. A572 gr. 50 and 316L SS were butt-welded successfully through Gas Metal Arc Welding using a pre-mixed Shielding gas mixture of Ar and CO_2 in a single pass.

ii. The issues like lack of penetration and high spatter were not observed for 316L SS samples welded at optimum parameters, and any crack or micro-fissuring in HAZ was also not found. Lower grain coarsening effect was found for optimum heat input around 6 kJ/cm and 10 kJ/cm.

iii. Microstructural characteristics of the heat-affected zone, such as grain growth, precipitation behaviour etc., were solely dependent on the temperature rise and cooling effect in HAZ during metal transfer.

iv. Good shielding of weld bead produced weld with negligible spatter and heat tint colour indicating the lack of loss of alloying elements during welding.

v. Finally, from the study, it can be deduced that pre-mixed Ar+CO_2 shielding gas composition may be utilized to obtain higher penetration in a productive and cost-effective way for the fabrication process for A572 gr. 50 and 316L SS steel.

Concluding Remarks

In the present work, A572 gr. 50 and 316L SS flats were successfully welded in single-pass under a pre-mixed shielding gas mixture of Ar and CO_2. The automatic welding of both materials shows very good weldability. The sample welded at optimum levels showed full penetration with uniform and homogeneous weld ripples at the top. The coarsening effect was observed in the heat-affected zone of both materials contributing to variation in mechanical properties, which were discussed in detail. The following conclusions were drawn from the present study.

- A572 gr. 50 with the highest UTS and YS of 435 MPa and 349 MPa respectively were welded using a gas mixture of 72%Ar+18%CO_2 with considerable improvement in UTS and YS of 11%.
- The current was the most influential parameter (60.87% contribution), followed by speed (22.69% contribution) and flow rate (11.43%), with considerable grain coarsening effect in HAZ.
- For A572 gr. 50 optimum UTS and YS, the parameters are Current 170 A, gas flow rate of 10 l/min and weld speed of 3.75 mm/sec, which was also verified through Taguchi's analysis, mechanical and microstructural study.
- Heat input played a major role in the decrease in UTS and YS due to the grain coarsening effect in CGHAZ at higher heat inputs. With an increase in welding current, there is a decrease in YS and UTS, and an increase in grain size in HAZ has been found. An increase in weld speed decreased heat input and followed a similar trend as current. A low gas flow rate was also sufficient to gain optimum strength providing enough protection.
- CGHAZ has a considerable drop in hardness due to high HI from 290 HV (in FGHAZ) to 180 HV (in CGHAZ), as a decrease in cooling rate caused greater grain coarsening in the heat-affected zone and decreased hardness by 37%, ultimately affecting the joint strength.
- 316L SS with the highest UTS and YS of 535 MPa and 275 MPa respectively were welded in single-pass using 78%Ar+12%CO_2 gas mixture with considerable improvement in ultimate tensile strength and yield strength.

- The mode of fracture in a fractured tensile specimen was ductile for both the base material and the welded samples shown by bright plastic flow lines. No ductile to brittle transition was observed for the welded samples.
- For SS316L also, the current was the most influential parameter (65.10% contribution), followed by weld speed (10.77% contribution) and gas flow rate (10.64%).
- For optimum UTS and YS, the parameters are Current- 145 A, Gas flow rate- 10 l/min and Weld speed of 2.5 mm/sec, which was also in agreement with Taguchi's analysis results.
- With an increase in welding current, there is a decrease in YS and UTS due to increased δ-ferrite volume percentage. Heat input increase, increased the unmixed zone and grain size in HAZ. The sample welded at optimum parameters contained δ ferrite around 6% by volume.
- A gradual drop in hardness (from 248 HV to 179 HV) was found from weld bead to base material as an increase in heat input affected the heat-affected zone, which ultimately affected the joint strength. A reduction in hardness was also observed due to an increase in grain size in HAZ.

5.2 Future Perspectives

Based on present research outputs, the future perspectives may be outlined as:

i. Special heat treatment can be developed for A572 and 316L. The microstructural and strengthening behaviour of HAZ can be studied after heat treatment.

ii. As the HAZ contains CG and FG structure, the microstructural inhomogeneity can be homogenized by adopting secondary processes, i.e. FSP, Rolling, Impact Trailing Method etc.

iii. As fusion-based arc welding generates thermal stress, which may influence the welded part's life, so the stress analysis is maybe the next window of research.

iv. Since A572 gr. 50 and SS316L are structural steel, so the HAZ and the nugget zone of weld metal may be screened through various other characterizations, i.e. Fracture toughness, Fatigue Analysis under different environmental conditions.

v. A complete 3D FE analysis of welding can be adopted to reduce the experimental cost and time.