MECHANICAL AND METALLURGICAL ASPECTS OF DISSIMILAR METAL WELDS A REVIEW

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ABSTRACT

A literature review of studies and researches has been attempted in the field of dissimilar metal welding. Dissimilar metal welds have numerous industrial applications in area of thermal power generation, chemical, petrochemical, automobile, aerospace industries and nuclear plants etc. The purpose of this paper is to review: (a) Dissimilar metal welds, their Metallurgical and Mechanical aspects using both GTAW and SMAW techniques, (b) Dissimilar metal welds, their Metallurgical and Mechanical aspects using GTAW technique, (c) Dissimilar metal welds, their Metallurgical and Mechanical aspects using SMAW technique.

Keywords: Dissimilar metal weldments, welding processes, mechanical and metallurgical properties.

1. Introduction:

Dissimilar metal welding refers to the joining of two alloy systems or we can say of different compositions. Dissimilar metals joints have tremendous applications which require certain appropriate combination of properties. Actually all fusion welds are dissimilar welds because metals being joined is wrought structure and welds have a cast structure. Various types of metals have different properties (physical, chemical, mechanical and metallurgical) out of which certain metals are more corrosion resistant and some are less. Preparing a dissimilar metal joint is to combine certain properties of metals in accordance to minimizing costs of material and maximizing performance of the machinery and equipments where this type of joint is being used. In the current scenario, the dissimilar metal joints can be prepared by various processes such as pressure welding, fusion welding, friction welding, explosion welding, and diffusion welding, soldering and brazing etc [1].

Dissimilar metal weldments have different applications in accordance to various properties, cost savings and performance enhancement. Certain applications of this type of joints include transport vehicles, pressure vessels, space crafts and earth moving equipment etc. The dissimilar metal welding is prominently used in fabrication, construction and erection of various structures. Tremendous applications of joining of dissimilar metals in various field of construction, including nuclear, offshore and spacecraft, provides huge scope for researchers to study behaviour of various types of metal joints working under different loading conditions [2]. Due to the capability of working at high temperatures, these types of dissimilar joints of metals have potential application in the power generation industry. Dissimilar metal welds are also used to join stainless steel pipe systems and low alloy steel reactor pressure vessel in a nuclear water reactor. The weldment joining water nozzles of boiler to safe ends in the entire recirculation system is one of its complex configurations. [3]

2. Dissimilar metal welds, their Metallurgical and
Mechanical aspects using both GTAW and SMAW techniques:

Jang et al. [1] have demonstrated the microstructure and spatial variations in mechanical properties of dissimilar metal joint of Inconel 82/182 of 316 stainless steel and low alloy steel. Dissimilar metal joint consists of low alloy steel, Inconel82/182 weld, and stainless steel which was prepared with help of shielded metal arc welding and gas tungsten arc welding processes. The dendritic structures were spotted in Inconel82/182 weld. Secondary phase precipitations and segregation occurred at areas between the dendrites. At fusion weld of Inconel, values of tensile strength and yield strength were 50–70MPa more at the bottom than at the top of weld. At room temperature fracture toughness values of 100–220 kJ/m2 comes out in Inconel 82/182 welds. It depends on the location of the weld along the direction of thickness. The fracture toughness of the weld at the top is 70% more than those at the bottom of the weld. The fracture surface of specimen showed the change in fracture from primary dimple mode to large shear-stretch mode because of increase in value of fracture toughness from the bottom to the top of the welds.

Sireesha et al. [2] have investigated thermal cycling of joint consisting Alloy 800 and 9Cr–1Mo (Grade 91) steel joined using Inconel 182 filler material. Butt joint with single V-groove was prepared between plates of normalised 1080 8C and annealed Alloy 800 and tempered (750 8C/1 h) Grade91 steel with help of gas-tungsten arc welding. Inconel 82 filler used for the pass of root and for manual metal arc welding and for subsequent passes Inconel 182 was used. No carbon diffusion was spotted during thermal cycling from ferritic steel to weld metal; hence carbon depletion and hardness drop have occurred. Increase in hardness values on sides of weld interface which can be correlated with strain hardening and certain precipitation of the weld metal. No oxide notch or cracking was spotted even at extreme conditions (post
weld tempering at temperature of 760 8C for 50 h and stress of ¼ 270 MPa, and thermal cycling of 625 8C/2750 h/125 cycles).

Lee et al. [3] have studied the creep–fatigue damage of joints of dissimilar metal of modified 316L stainless steel and 9Cr–1Mo steel prepared by GTAW and SMAW techniques. He found that the total strain values reported to be more in ASME-NH calculation as compared to RCC-MR calculation of a same weld. The values of elastic–plastic strain of ASME-NH were much higher than RCC-MR. The creep strain values of RCC-MR come out to be more severe than ASME-NH. The fatigue life time and time of creep rupture was affected by magnitude of a strain affects. ASME-NH shows better results of a fatigue life time as compared to RCC-MR.

Timofeev et al. [4] have discussed the mechanical and corrosion strength of joints of down comers of RBMK reactor. These joints were prepared of austenitic stainless steel by MAW and TIG welding processes. Because of damage from the effect of corrosion, mechanical and microstructural factors there was development and formation of piping welded joints of $\phi$325 X16 mm. Saturation with oxygen amount ranging 0.2–0.3 mg/kg achieved reveals the rate of failure of HAZ corrosion at the inner surface of joints of $\phi$325X16 mm down comers. Rise in oxygen content in the water circulation makes impact on time span of period of incubation of ISCC. ISCC cracking was discrete in nature. In hydraulic tests initiation of crack growth takes place. A decrease in rate of crack growth was observed with increasing depth.

Karthik et al. [5] have demonstrated the comparative evaluation of mechanical and microstructural properties of SA213T91 and SA213T22. The dissimilar metal weldments between SA213T91 and SA213T22 by SMAW, GTAW and their combinations by using varied welding electrode/ wires was successful. He found that as none of the combinations of the weldment have fractured from central weld metal, which justifies the acceptability of all the combinations. The microstructural variations along the different sections of all the combinations of the weldment are dependable on the welding technique, thermal cycles of process, chemical composition of base metals and welding electrodes. The micro-hardness of HAZ on T91 side of the weldments is highest, which is due to martensitic structure of that region. The ductility of all the combinations of the weldment is less than the respective ductility of the base metals. The micro-hardness profile of GTAW and GTAW+SMAW presents uniformity in its shape and values. A carbon denuded soft zone is observed at the interfaces of T91 BM/ T91 HAZ and of T22 BM/ T22 HAZ in the weldments welded by SMAW process. The micro-hardness on HAZs i.e. on both sides of weld metal of all the weldments is high than their respective base metals.

Mittal et al. [7] have investigated the microstructural and mechanical properties of weldments of ferritic steels of SA213T91 and SA213T22. The dissimilar metal weldments between SA213T91 and SA213T22 by SMAW, GTAW and their combinations by using varied welding electrode/ wires was successful. He found that as none of the combinations of the weldment have fractured from central weld metal, which justifies the acceptability of all the combinations. The microstructural variations along the different sections of all the combinations of the weldment are dependable on the welding technique, thermal cycles of process, chemical composition of base metals and welding electrodes. The micro-hardness of HAZ on T91 side of the weldments is highest, which is due to martensitic structure of that region. The ductility of all the combinations of the weldment is less than the respective ductility of the base metals. The micro-hardness profile of GTAW and GTAW+SMAW presents uniformity in its shape and values. A carbon denuded soft zone is observed at the interfaces of T91 BM/ T91 HAZ and of T22 BM/ T22 HAZ in the weldments welded by SMAW process. The micro-hardness on HAZs i.e. on both sides of weld metal of all the weldments is high than their respective base metals.

Mittal et al. [9] have demonstrated the microstructures and mechanical properties of dissimilar T91/347H steel weldments. Welding of SA213T91 with AISI 347H by SMAW, GTAW and their combination by using different welding electrodes/wires seems to be successful. He found that the micro-hardness of the heat affected zone on T91 side of all the combination of weldments is due to needle
shaped martensitic structure of the HAZ. The GTAW, ERNiCr3 weldment achieved the highest tensile strength and ductility than all other combinations of the weldments. The ductility of all the weldments except GTAW, ERNiCr3 is less than the ductility of respective base metals. The observed presence of martensite phase along with carbides in the HAZ of T91 side is another probable reason for the higher micro-hardness. As an overall dissimilar metal joints produced by GTAW with filler wire of ERNiCr3 has given better results.

3. Dissimilar metal welds, their Metallurgical and Mechanical aspects using GTAW process:

Timofeev et al. [10] have studied the mechanical and corrosion strength of joints of downcomers in RBMK reactor which was prepared using austenitic stainless steel by TIG and MIG welding techniques. Current for root bead of 45-90 A, other beads of 90-100A, argon flow rate of 8-10 L/min were used for manual welding using TIG and for automatic TIG welding the current of 50-95 A for root bead and of 115-135 A for other beads were used. Formation of Cr-carbides and grain growth takes place in multipass welding which generally favours corrosion crack growth. Smaller number of beads, large metal deposition and a lower influence of heat near weld zone was provided in covered electrode TIG welding, as compared to manual TIG. Occurrence of crack in sensitization zone takes place in all the cases.

Deepashri Nage et al. [11] have discussed the effect of nitrogen addition on the mechanical and microstructure properties of 316L austenitic SS welds which was prepared by TIG welding with use of 317L and 904L filler wires of 3.2 mm diameter. Welding speed of 4.3 mm/s, argon flow rate of 8 L/min, electrode gap of 4.5 mm, current of 145 & 160 A for 317L and 904L (without N addition) and of 140 & 155 A for 904L and 317L welds were used as welding parameters with N as addition into shielding gas. Higher values of strength and hardness of the 317L weld was observed as compared to 904L welds due to 317L weld was spotted with two phase structure but 904L weld with structure of single phase. For 904L the welding current was more than 317L. Therefore percentage dilution was more for 904L welds.

Sathiya et al. [12] have demonstrated the effect of shielding gases on metallurgical and mechanical properties of duplex stainless steel joint using Tungsten inert gas welding with Zeron-100 wire of 3mm diameter. Two different types of shielding gases (helium and argon) were used during welding with two different welding parameters. This study reveals that the depth of penetration was 4.499 mm and the bead width of the argon-shielded weld was 12.43 mm. The depth of penetration was 4.556 mm and the bead width of the helium-shielded weld was 18.82 mm. By using helium shielding large penetration with wider bead width was obtained because to the higher arc energy. The helium-shielded specimen possesses more toughness as compared to argon-shielded weld due to high cooling rate, large arc energy and excess amount of Mn in the WZ. Hardness observed is higher of weld metal as compared to base material and HAZ for both the helium and argon shielded cases. Hardness value of the argon shielded weld is comparatively less than that of the helium shielded weld because of less austenite phase in Ar shielded welds. The austenite structure was observed in the microstructure of the helium shielded weld because of high arc energy.

Srinivasan et al. [13] have investigated the micro-hardness and microstructural in a dissimilar metal joint of 316 austenitic SS and 410 martensitic SS using autogeneous gas tungsten arc welding (GTAW) process. Type-II boundary was developed at the interface in-between martensitic stainless steel (MSS) and weld metal which was revealed from optical micrographs. In the MSS the heat affected zone (HAZ) near fusion boundary possesses coarse martensitic structure whereas the heat affected zone in the austenitic stainless steel (ASS) near the fusion boundary had a fine dendrite of ferrite and austenite structure. This reveals that there might be difference in composition of these regions and also the solidification mode could have been different. Higher value of micro hardness of the weld metal was observed than in base metals, this may be due to absence of martensite in this region. Weld metal region have consists essentially of austenite with little amount of ferrite.

Lakshminarayanan et al. [14] have studied the effect of constant current, pulse current in GTAW and plasma arc welding processes on mechanical properties such as impact and tensile strength of ferritic SS joints. The welding parameters, current of 150 A, voltage of 24 V, speed of welding of 200 mm/min, electrode diameter of 3mm and gas flow rate of 14 L/min were used for GTAW and for PAW current of 150 A, voltage of 24 V, welding speed of 300 mm/min, gas flow rate of 18 L/min and electrode diameter of 2.5 mm were used. Tensile strength, elongation, toughness and hardness of the pulse current GTAW weld was comparatively higher than that of constant current GTAW weld because of heat input supplied by the CCGTAW is more than the PCGTAW process.

Qinglei et al. [15] have studied the dissimilar welding joint of 18-8 stainless steel and Mo-Cu composite prepared by TIG (Tungsten Inert Gas) welding process with use of Cr-Ni filler wire. Microstructure, microhardness values of the joint was analysed. The arc voltage of 28-32 V, welding current of 90A, argon gas flow rate of 8L/min and welding speed of 0.83-1.07 mm/sec was used for joint preparation. The optical micrographs revealed the netted ferrite and austenite structures were observed in weld metal. In the fusion zone
near Mo-Cu composite (HAZ), ferrite and austenite type of microstructure was revealed. During cooling carbon diffusion migration results in carbonized layer formation in the fusion zone near to decarburized layer and weld metal was spotted in the weld metal. Ferrite layers were observed in the weld metal close to the fusion zone due to decarburization. Microhardness values increases moving from the weld metal towards the boundary of fusion zone close to Mo-Cu composite. Microhardness reached the value of 1225HV close to boundary of Mo-Cu composite near fusion zone because of the formation of Fe-Mo intermetallic compound.

Wang et al. [16] have discussed the effect of Tungsten Inert Gas (TIG) welding parameters (current, impulse frequency, welding speed, weld remelting number) and grooves on morphology, microstructure and tensile strength) of joint of GH99 Ni-based super alloy. He found that root of joint was not welded because of low welding current. The elongation and strength of welded joint were inferior. When the current is high, more melt metal penetrates which results in collapse of the front face of seam which causes stress concentration and the strength of joint is degraded. The heat input is inversely proportional to speed of welding and directly to the welding current. The increase in impulse frequency lowers the strength and elongation.

4. Dissimilar metal welds, their Metallurgical and Mechanical aspects using SMAW process:

Missori and Sili et al. [17] have investigated the mechanical and microstructure properties of welding joints made of plates of 6082-T6 Alloy welded with GMAW (Gas Metal Arc Welding). The value of tensile strength of welded joints of 6082-T6 Al alloy undergoes a decrease of the initial value. The value of residual stress of joint was 60% of the parent metal, which indicates the reduction in allowable design stress by 57% for the welded joints. Minimum tensile strength and hardness was recorded at 6 mm distance from the weld fusion line, due to over-aging consequent to the transformation of the strengthening metastable precipitate.

Anwar Ul-Hamid et al. [18] have investigated the butt joints between 304 stainless steel and carbon steel pipe and its failure at elbows by use of arc welding process with use of ER309 filler metal and E309 electrodes. Circumferential cracks were signified by light optical microscopy at low magnification near the weld region in CS pipe. SEM/EDS analysis of the surface which was fractured revealed the presence of Ni and Cr. Microstructure of CS-SS interface shows the formation of crack from the inner surface of pipe and moving towards the outer surface. The occurrence of crack at the interface between SS and the carbon weld and its propagation was transgranular. The C-S steel fusion zone results in low hardness pearlite-dened ferrite region. The decarburization during the welding process occurred where the segregation of carbon towards the SS weld was spotted. This resulted in a carbon rich segregated layer at interface. Hardness of Rockwell C 60 depicts the presence of martensite. The fracture have initiated within this martensitic zone. The results reveals that small region of high hardness produced at the CS–weld interface initiate cracking.

Anna et al. [19] have discussed the characterization of structural and chemical fluxes for submerged-arc welding. A sintered and commercial flux was used for comparative evaluation. The four types of fluxes were studied chemically with help of X ray diffraction and atomic absorption techniques in order to calculate the type and quantity of oxides formed, and also variation in oxidation number at the sintering process at 950°C. Thermal analysis was carried out from 1000 to 1350°C for determination of temperatures for phase transformation sand melting of compounds formed during sintering process. Flux characterization helps us in quantification of the ions that may be present in the plasma arc during the welding process.

Taban et al. [20] have studied mechanical and metallurgical aspects of modified X2CrNil2 ferritic stainless steel and carbon content below 0.015% welded to non-alloy S355 steel by shielded metal arc (SMA) and submerged arc (SA) welding processes with help of AISI309 type of filler metal. Microstructural analysis was done with help of macro and micrographs, hardness values and ferrite content measurements, and grain size examination. Charpy impact and crack tip opening displacement (CTOD) fracture toughness tests, tensile, and bend tests were done for analysis. Salt spray and blister tests were used for corrosion testing in order to check weld properties of the joints. During cross-weld tensile testing all specimen broke in the base metals. Charpy impact values at HAZ vary from 17 to 30 J and correlated with the microstructure analysis.

Magudeeswaran et al. [21] have investigated high cycle fatigue properties of high strength, Quenched and Tempered (Q&T) steel joints and its effect because of welding consumables. Quenched and Tempered steels are wide applications in making of military vehicles because of their high strength-to-weight ratio and high hardness values. Hydrogen-induced cracking generally occurs in these steels at heat affected zone (HAZ) after welding. This can be prevented by use of austenitic stainless steel consumables to weld the above steel due to higher solubility for hydrogen in austenitic phase. Recent research have proved that high nickel steel and low hydrogen ferritic steel consumables can be applied to weld Q&T steels. In three different consumables namely (i) austenitic stainless steel, (ii) low hydrogen ferritic steel, and (iii) high nickel steel were used
to fabricate the joints by shielded metal arc (SMAW) welding process. **Falat et al.** [22] have discussed microstructure and creep behaviour of dissimilar weldment between martensitic steel T91 and austenitic steel TP316H with Ni-based weld metal and its characterisation. Microstructure analysis was done with help of Light microscopy, scanning and transmission electron microscopy and X-ray spectroscopy. The martensitic part of the welded joint possesses a wide heat-affected zone (HAZ) along with microstructural gradient of coarse-grained to the fine-grained/inter critical region. The microstructure of Ni WM comes out to be heterogeneous in accordance to the size, morphology and distribution of grain boundaries. Also, MC-type precipitates because of strong weld metal dilution and fast non-equilibrium solidification.

5. Conclusion:

This paper provides a detailed literature review in the field of dissimilar metal weldments done by various researchers. The analysis of variety of dissimilar metal joints, appropriate welding processes, variations in mechanical and metallurgical properties has been shared. The analysis of effect on mechanical and metallurgical aspects of dissimilar metal welds due to SMAW and GTAW techniques has been shared. This paper has presented the comparison between SMAW and GTAW techniques to built a stronger dissimilar metal joint.

References


