Analysis of mechanical and metallurgical properties of alloy steel material welded by STT welding process

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Abstract - *High strength alloy steel materials are widely used in applications such as thermal power plants, nuclear reactors, space crafts and etc. Conventional method of welding the weld joints of pressure pipe headers in thermal power plants has been carried out by using Gas Tungsten Arc Welding (GTAW) root pass followed subsequent passes by Shielded Metal Arc Welding (SMAW) processes. In order to develop an alternate method, a full Gas Metal Arc Welding (GMAW) technology (Modified short arc process as Surface Tension Transfer (STT) root pass followed subsequent passes by pulsed current GMAW process) for welding alloy steel have been established and weld quality is analyzed. This paper deals with the analysis of weld defects and study of mechanical and metallurgical properties of the alloy steel material welded by modified GMAW process*

Key Words*: *Alloy steel, STT welding process, Pulsed GMAW, Mechanical and metallurgical properties

1. INTRODUCTION

Alloy steel is steel containing specified quantities of elements (other than carbon and commonly accepted amounts of manganese, copper, silicon, sulphur and phosphorus) within the limits recognized for constructional alloy steels added to effect changes in mechanical or physical properties[1]. As a guideline, alloying elements are added in lower percentages (less than 5%) to increase strength or harden ability, or in larger percentages (over 5%) to achieve special properties, such as corrosion resistance or extreme temperature stability. Manganese, silicon, or aluminum are added during the steel making process to remove dissolved oxygen, sulphur and phosphorus from the melt. Manganese, silicon, nickel, and copper are added to increase strength by forming solid solutions in ferrite. Chromium, vanadium, molybdenum, and tungsten increase strength by forming second-phase carbides. Nickel and copper improve corrosion resistance in small quantities. Molybdenum helps to resist embrittlement. Zirconium, cerium, and calcium increase toughness by controlling the shape of inclusions. Sulfur, in the form of manganese sulfide, lead, bismuth, selenium, and tellurium, increases machinability [2].

Material composition of alloy steel grade 22 used in thermal power plants is tabulated below.

Table -1: Composition of Alloy steel Gr. 22 material

Elements	Composition in % of weight
Carbon (C)	0.15 %
Manganese (Mn)	0.30 – 0.60%
Phosphorus (P)	0.035%
Sulfur (S)	0.035%
Silicon (Si)	0.50%
Chromium (Cr)	2.00 – 2.50%
Molybdenum (Mo)	0.90 – 1.105

2. STT WELDING PROCESS

STT (Surface Tension Transfer) welding process is a modern, highly efficient and high quality welding process for thin wall materials joining and joining at root passes of thick materials. STT welding power source provide stabile main welding parameters during welding process which enable welding by “short circuit arc”. The material transfer in electric arc is founded on surface tension force between weld pool and melted bead in electric arc. STT unit frequently and precisely controls welding current during welding. It sets an optimal welding parameters (which are stabile) by significant changing of arc length and “stick out”. Principally, it is welding unit with possibility of welding parameters changing in milliseconds in order to obtain an optimal quality of welded joint. It is designed as a semi-automatic welding process for application where welding speed and “stick out” are variable. At STT welding process, it is possible to use different shielding gases and gases mixtures depending on application [3]. Welding processes suitable for individual pipes joining and pipes joining in pipes systems (membrane wall, membrane panel) are interesting in steam boiler production which is a specific type of production due to different material types, thickness and weld joint shapes. Conventional approach for pipes joining in steam boiler industry up to ø 88 mm is manual or automatic TIG welding process (Tungsten Inert Gas) as a single bead or multi bead process. For joining higher diameter pipes in steam boiler industry, combination of welding processes TIG and SMAW

(Shielding Metal Arc Welding) or TIG + SMAW + SAW (Submerged Arc Welding) is usually used, depending on available equipment. Manual TIG welding process is used for root passes which are the most important and the most complex from the standpoint of weld ability (welding in non-accessible areas, denivelation in that joint area is the most evident, gap in weld joint root must be in rigid tolerance, preheating and gas shielding from root joint pipe side aggravate welding). STT welding process is process which will replace manual TIG welding process in described situation.

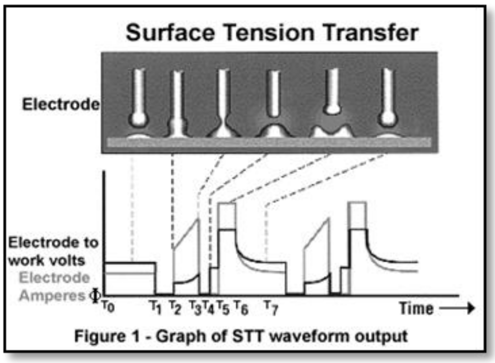


Fig -1: Distribution of welding parameters in STT welding process [4]

3. DESIGN METHODOLOGY

The advantage of using full Gas Metal Arc Welding (GMAW) process is producing comparatively faster, long, clean, continuous weld of thick wall alloy steel pipe with respect to conventionally used Shielded Metal Arc Welding (SMAW) process has been established. However, the necessity of applying the conventional GMAW process in short and spray modes of metal transfer in welding of root and filler passes respectively has led to high spatter, burn through and large amount of metal deposition. Control of the adverse influence of conventional GMAW on required weld joint quality has been successfully addressed by application of surface tension transfer (STT) for root pass followed by pulsed current GMAW (P-GMAW) process for filler passes. In order to increase the productivity with desired weld joint quality, the semi- automatic welding positioner is used. Prior to its application the suitability and effectiveness of the positioner with respect to speed control and GMAW torch head manipulation in groove was tested. After that, by using the positioner, full GMAW technology for pipe butt welding were established. The quality of weld joints has been checked and analyzed by X-ray radiography. Further, to qualify the weld joint conventional mechanical testing such as tensile test, bend test and micro hardness test has been carried out. Also, microstructural analysis have been carried out to study the metallurgical properties of alloy steel material and weldment [5].

4. DESIGN OF EXPERIMENT

For selecting the optimum parameter for welding of alloy steel pipe butt weld joints, Taguchi orthogonal L4 array has been selected with three factors and 2 levels [6]. The three factors are namely, welding current, welding voltage and travel speed. From output, properties like bead width, bead height and penetration was calculated. Based on the necessary penetration, bead width and bead height the parameters were selected. The optimum parameters for the welding were around Current 220 A, Voltage 36 V and Travel speed 28 mm/min

Table -2: Taguchi L4 Orthogonal array method

Welding Current, A	Welding Voltage, V	Travel speed, mm/min
200	36	26
200	38	28
220	36	28
220	38	26

5. MODIFIED GMAW PROCESS

A semi-automatic welding positioner along with torch head attachment is used for the welding process. The welding positioner consists of a three jaw chuck, electrical motor assembly, speed controller box with digital display and torch holding device. The positioner can operate with various welding speeds by controlling the knob fitted within speed controller box

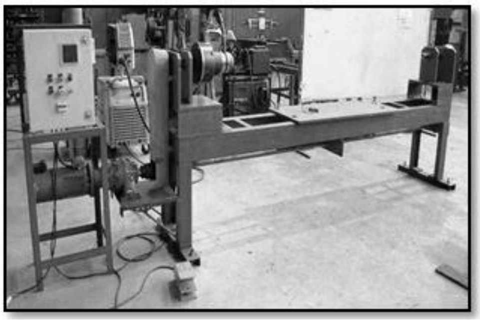


Fig -2: Photographic view of Semi-automatic welding positioner

Weld groove has been prepared as per conventional groove design for edge preparation. Prior to welding, the groove surface was checked visually followed by acetone cleaning to ensure the clean groove wall. The welding was carried out by multi-pass GMA welding process. During welding the pipes were held horizontally with the help of three jaws clamping system in a rotating table and the welding was carried out in 1GR position.

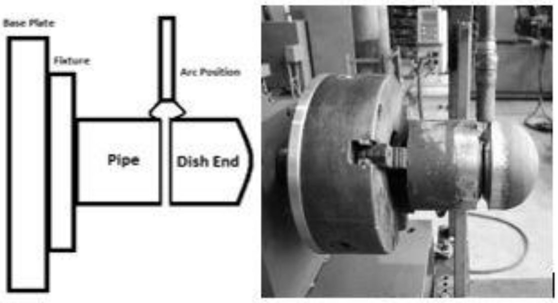


Fig -3: Experimental setup of modified GMAW process

6. RESULTS AND DISCUSSIONS

The welded specimens are tested for radiography, mechanical and metallurgical properties and collection of differently oriented specimens for mechanical and metallographic testing from different location of the weld in reference to the weld joint has been schematically shown below.

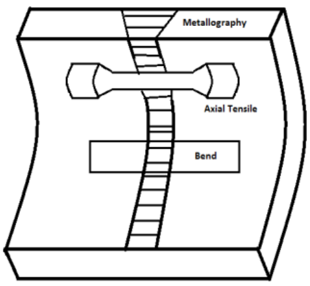


Fig -4: Schematic representation of test specimens collected for testing

6.1 Analysis of weld defects

The radiographs depicts significant amount of weld defects such as burn through, lack of fusion and incomplete penetration in the specimens in which optimum weld parameters were not selected. After analyzing the weld defects in the radiography of the weld joint, the optimum range of welding parameters and procedure have been derived to achieve defect free weld joint.

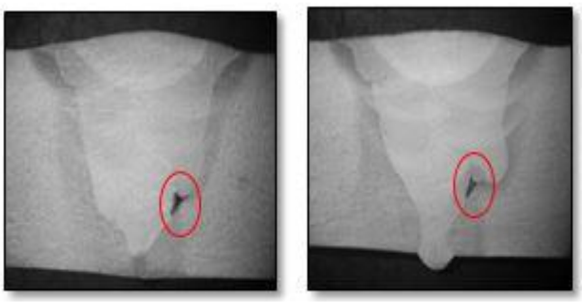


Fig -5: Radiograph of weld defect specimens

6.2 Studies on mechanical properties

As per AWS B4.0 standard tensile testing of the axial weld joint having weld at its center has been carried out using flat tensile test specimens [7]. The axial tensile property of the weld joints welded by full GMAW process is done in Universal Testing Machine UTE-60. It is observed that, fracture occurred in base metal and not in the weld joints as shown in fig.6

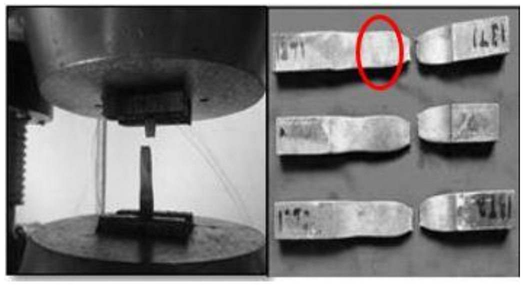


Fig -6: Tensile testing of weld specimen showing fractured location

Yield strength and ultimate tensile strength of the alloy steel weld joints (after PWHT) of the specimen welded by STT root pass followed by Pulsed GMAW process is tabulated below. The values depicts that the axial tensile strength of the weld specimen is acceptable and meets the quality requirement.

Table -3: Tensile strength of weld specimen

S.NO	Yield strength in Mpa	Ultimate Tensile strength, in Mpa	Result
1	350	465	Accepted
2	363	483	Accepted
3	354	478	Accepted

The bend tests of pipe weld joint has been carried out as per AWS B4.0 standard in universal bending machine [7]. The bend results of the weld joints prepared by full GMAW procedure are as also shown in fig.7. It is observed that, after bending the weld specimens are not showing any open discontinuity or cracks. Thus, it infers that the weld joints prepared by full GMAW procedure showed good formability.

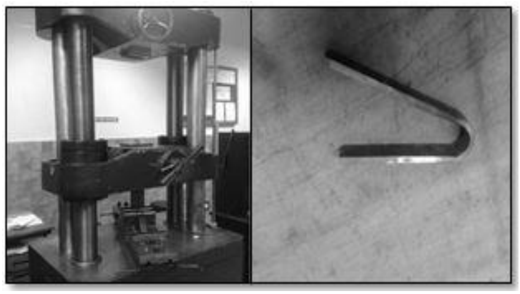


Fig -7: Bend testing of weld specimen

Micro indention hardness measurement is performed across the welds to obtain the hardness profiles in the weld metal, heat affected zone, and the base metal at a load of 200g in the interval 500 micron distance by using micro indention hardness tester the ASTM E92 standard [8].

Fig -8: Testing the weld specimens in Vickers Hardness tester

Vickers hardness curve HAZ area is having more hardness compared to weld metal and base metal. Its value ranges from 187 to 195 VHN. The graph also depicts weldment is having more hardness compared to base metal. Its value ranges from 169 to 175 VHN

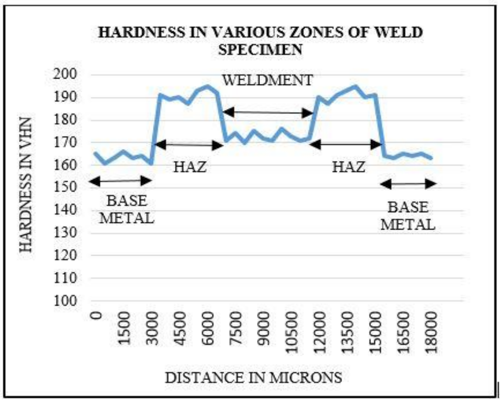


Chart-1: Vickers hardness curve for the weld specimen

6.3 Studies on macrostructure

According to ASTM E340 standard, the weld specimens were selected to evaluate HAZ width by macro test. A Stereo microscope was used to examine the HAZ width, bead length, reinforcement, angle of weld and bead depth from the specimens. Therefore, for each joint, one specimen with proper size prepared by grinding using 100 – 900 grits silicon carbide paper, followed by 1 µm alumina powders. The specimens are etched for 15s using nital solution (2% nitric acid in alcohol) to show the structure of alloy steel and also they are etched by solution oxalic acid and electro etched microstructure of SS321H [9].

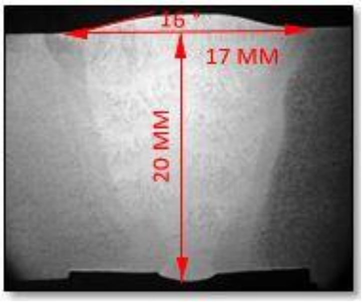
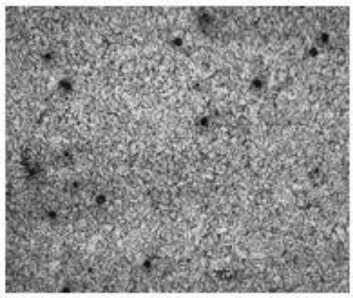


Fig -9: Macrostructure of the weld specimen

6.4 Studies on microstructure

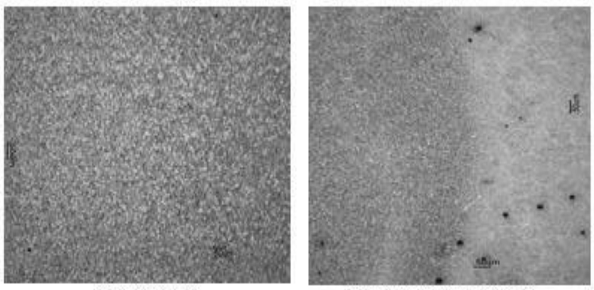
Micro test of the weld specimen is conducted by optical microscope at different focal length to find out the microstructure present in the base metal, HAZ, weld interface and weldment. Metallographic procedure is used for the studying microstructural analysis. Microstructure of alloy steel base metal shows tempered martensitic structure with carbides decorating the boundaries and as well as inside the grains.



Base metal (200 x)

Fig -10: Microstructure of the alloy steel base metal

Microstructure of coarse grained HAZ of the specimen having the structure of completely transformed un-tempered lath like martensitic structure with little amount of polymorphic structure with large prior austenite grain boundaries is shown in fig.11 .Grain boundary is having ferrite and widmanstatten acicular ferrite with little bit of bainite structure. Also, the microstructure of base metal and weld interface shows predominantly ferritic structure.



HAZ (200 x) Weld interface (200 x)

Fig -11: Microstructure of the HAZ and weld interface

Analysis of microstructure in the weldment of the alloy steel specimen have been carried out in two locations namely, at root of the weldment and top of the weld. The microstructure of weldment at root section shows that weld is having predominantly untempered martensitic structure. Weldment having highly refined ferritic structure at both the locations.

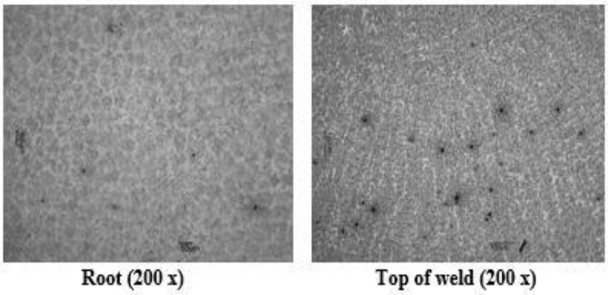


Fig -12: Microstructure of the weldment at root and top of the weld

The microstructure of HAZ area near top and bottom of the weld shows no variation and both are having same martensitic structure as discussed above.

7. CONCLUSIONS

Thus, full Gas Metal Arc Welding (GMAW) technology (Modified short arc process as Surface Tension Transfer (STT) root pass followed subsequent passes by pulsed current GMAW process) have been established for welding alloy steel material. The weld joints prepared by full GMAW technology meet required radiography and mechanical properties such as tensile strength, hardness and bend formability. The studies on macrostructure and microstructure depict metallurgical characteristics of the alloy steel material welded by modified GMAW process. Thus, it is equivalent for the conventional time consuming welding process of GTAW root pass followed by SMAW process. Also it is concluded that there is a significant improvement in weld quality and productivity with reduced cycle time by using modified GMAW process

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