Analysis of Dissimilar Metal Welding of 1020 Mild Steel and 304 Stainless Steel

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Abstract— Joining of different metals has discovered its utilization broadly in power age, electronic, atomic reactors, petrochemical and synthetic ventures essentially to get customized properties in a segment and decrease in weight. Anyway proficient welding of unique metals has represented a significant test because of contrast in thermo-mechanical and substance properties of the materials to be joined under a typical welding condition. This causes a precarious slope of the thermo-mechanical properties along the weld. An assortment of issues come up in unique welding like splitting, huge weld remaining anxieties, relocation of iotas during welding causing pressure focus on one side of the weld, compressive and elastic warm burdens, stress erosion breaking, and so forth. Weld remaining pressure and warm pressure have been dissected for unique metal welding of 304 tempered steel to 1020 gentle steel accepting 302 hardened steel as the filler metal. Essentially taking strain created as a list the powerlessness of the welded joint to pressure erosion splitting have been considered. It is discovered that when the filler metal is supplanted by Inconel 625 noteworthy improvement is acquired in the welded joint regarding decrease in pressure created and stress consumption splitting. Likewise the issue of carbon movement is disposed of by the utilization of Inconel 625 as a weld filler metal because of the opposition of nickel-based combinations to any carbon dissemination through them.
Keywords: Mild Steel and Stainless Steel

I. INTRODUCTION

Welding is an assembling procedure of making a changeless joint got by the combination of the outside of the parts to be consolidated, with or without the utilization of weight and a filler material. The materials to be joined might be comparable or unlike one another. The warmth required for the combination of the material might be gotten by consuming of gas or by an electric circular segment. The last technique is all the more widely utilized as a result of more noteworthy welding speed.

Welding is broadly utilized in creation as an elective technique for giving or producing and a role as a trade for darted and bolted joints. It is likewise utilized as a fix medium for example to rejoin a metal at a make or to construct laugh out loud a little part that has severed, for example, an apparatus tooth or to fix a well used surface, for example, a heading surface.

A. Weld Processes

The welding procedures might be extensively characterized into the accompanying two gatherings:

Welding forms that utilization heat alone for example Combination Welding. Welding forms that utilization a mix of warmth and weight for example Manufacture Welding.

B. Fusion Welding

In case of fusion welding the parts to be joined are held in position while the molten metal is supplied to the joint. The molten metal may come from the parts themselves i.e. parent metal or filler metal which normally has the same or nearly similar composition as that of the parent metal. Thus, when the molten metal solidifies or fuses, the joint is formed. The fusion welding, according to the method of heat generated, may be classified as:

1) Thermite Welding
2) Gas Welding
3) Electric Arc Welding

C. Forge Welding

In forge welding, the parts to be joined are first heated to a proper temperature in a furnace and then hammered. Electric Resistance Welding is an example of forge welding. The principle of applying heat and pressure, either sequentially or simultaneously is widely used in the processes known as Spot, Seam, Projection, Upset and Flash Welding.

Welded Joints: The welding joint geometry can be classified primarily into five types. This is based on the orientation between the material surfaces to be joined. The various joints are shown in the figure 1 below:

1) Lap Joint
2) Butt Joint
3) Corner Joint
4) Edge Joint
5) T-Joint

The main considerations involved in the selection of a particular welded joint are given below:

1) The shape of the welded component required,
2) The thickness of the plates to be welded, and
3) The direction of the forces to which the finished object will be subjected to in the actual working conditions.

D. Metallurgy of a Welded Joint

Metal is warmed over the scope of temperature up to combination and followed by cooling surrounding temperature. Because of differential warming, the material away from the weld globule will be hot however as the weld dab is moved toward dynamically higher temperatures are acquired, bringing about a complex miniaturized scale structure. The ensuing warming and cooling brings about setting up inward burdens and plastic strain in the weld.

Contingent on the incline of temperature angle three unmistakable zones as appeared in

1) welded joint
2) Base metal
3) Heat Affected Zone (HAZ)
4) Weld metal

A joint created without a filler metal is called autogenous and its weld zone is made out of re-hardened base metal. A joint made with a filler metal is called weld metal. Since focal segment of the weld globule will be cooled gradually, long columnar grains will created and in the out ward bearing grains will get better and better with separation.

So the pliability and strength diminishes away from the weld dab. Anyway quality increments with the good ways from the weld globule. The first structure in prepares comprising of ferrite and pearlite is changed to alpha iron. The weld metal in the liquid state has a decent propensity to break up gases which come into contact with it like oxygen, nitrogen and hydrogen.

So during hardening, a part of these gases get caught into the globule called porosity. Porosity is liable for decline in the quality of the weld joint. Cooling rates can be constrained by preheating of the base metal welding interface before welding.

The warmth influenced zone is inside the base metal itself. It has a microstructure not quite the same as that of the base metal subsequent to welding, since it is exposed to raised temperature for a generous timeframe during welding. In the warmth influenced zone, the warmth applied during welding recrystallizes the extended grains of the base metal, grains that are away from the weld metal will recrystallizes into fine equiaxed grains.

E. Dissimilar Welding

Joining of divergent metals has discovered its utilization widely in power age, electronic, atomic reactors, petrochemical and concoction enterprises chiefly to get customized properties in a segment and decrease in weight. Anyway productive welding of divergent metals has represented a significant test because of contrast in thermo-mechanical and concoction properties of the materials to be joined under a typical welding condition. This causes a precarious inclination of the thermo-mechanical properties along the weld. An assortment of issues come up in disparate welding like breaking, huge weld leftover burdens, relocation of molecules during welding causing pressure fixation on one side of the weld, compressive and ductile warm anxieties, stress consumption splitting, and so on. Presently before talking about these issues coming up during divergent welding, the entries coming underneath illuminate a portion of the reasons for these issues. In disparate welds, weldability is controlled by precious stone structure, nuclear measurement and compositional dissolvability of the parent metals in the strong and fluid states. Dispersion in the weld pool regularly brings about the arrangement of intermetallic stages, most of which are hard and weak and are therefore impeding to the mechanical quality and malleability of the joint. The warm extension coefficient and warm conductivity of the materials being joined are extraordinary, which causes huge oddball strains and thus the leftover burdens brings about breaking during hardening.

F. Stresses for Welded Joints

The worries in welded joints are hard to decide in view of the variable and unusual parameters like homogeneity of the weld metal, warm worries in the welds, changes in physical properties because of high pace of cooling, and so on. In structure issues, these anxieties are acquired on the accompanying suspicions:

The heap is dispersed consistently along the whole length of the weld, and the stress is spread consistently over its powerful segment.

G. Residual Stress

Lingering pressure is a pressure or pressure that exists in a material with no outer burden being applied, and the leftover worries in a segment or structure are brought about by inconsistent inner perpetual strains. Welding, which is one of the most huge reason for lingering pressure, ordinarily creates huge malleable anxieties, the greatest estimation of which is around equivalent to the yield quality of materials that are joined by lower compressive remaining worries in a part. The lingering worry of welding can altogether disable the presentation and dependability of welded structures. Two of the serious issues of any welding procedure are remaining pressure and contortion. Lingering pressure is essentially brought about by the compressive yielding that happens around the liquid zone as the material warms and extends during welding. At the point when the weld metal cools it contracts which causes a malleable leftover pressure, especially in the longitudinal course. Subsequent to welding a leftover elastic pressure stays over the weld centre line and causes an adjusting compressive pressure further from the weld zone. The elastic remaining weight on the weld line lessens the weakness quality and the durability, especially when joined with any indents or deformities related with the weld dot. To alleviate a portion of the lingering stresses brought about by the welding procedure, the structure misshapes, causing mutilation. There are a few methods of bending, however the one that is generally normal, especially in slim welded structures is clasping contortion, which is brought about by the compressive worry in the parent material. The leftover pressure created subsequent to welding is appeared in Fig 3 (b).

H. Thermal Stresses

In disparate metal welding, one of the metals in contact at the weld metal interface is compelled by extension or compression of the other. The two metals being welded have diverse coefficient of warm development. The metal having a higher coefficient of warm extension, with its inclination to extend more than the other is obliged by the fixed limit.
Because of which compressive warm pressure is created in the metal having a higher coefficient of warm extension while malleable warm pressure is created in the metal with the lower coefficient of warm development. The warm pressure created during the welding is appeared in .Thermal Stress Superimposed under Residual Stress .The welded metal parts are exposed to a various patterns of warm development and constriction. As consequence of which these warm anxieties get superimposed over the leftover pressure actuated in the wake of welding. A right gauge of warm worries under superimposed condition with the lingering pressure is important to decide the most fragile zone or the territory generally vulnerable to breaking. The cyclic warm anxieties superimpose on the weld remaining pressure and working pliable burdens can advance fragile break, increment the powerlessness of a weld to weariness harm and stress consumption splitting (SCC) during

administration. This will guarantee a sound plan of the joint and auxiliary uprightness.

Stress Corrosion Cracking (SCC) Stress erosion breaking is splitting because of a procedure including conjoint consumption and stressing of a metal because of remaining or applied anxieties. The effect of SCC on a material as a rule falls between dry splitting and the exhaustion edge of that material. SCC as a rule happens in certain particular composite condition pressure mixes. SCC is a consumption instrument that requires the blending of a material with a specific domain and the utilization of a pliable worry over a basic worth.

Stress Corrosion Cracking isn't only a material issue, however it is a consolidated aftereffect of the accompanying three components:

1) Material Properties
2) Corrosive Environment
3) Stresses

The vast majority of the surface isn't assaulted, yet with fine splits entering into the material. In the microstructure, these breaks can have an intra-granular or a trans-granular morphology. Perceptibly, SCC breaks have a weak appearance. SCC is delegated a cataclysmic type of consumption, as the recognition of such fine breaks can be extremely troublesome and the harm not effortlessly anticipated. Run of the mill SCC disappointments are found in pressure vessels, pipework, focused on parts and frameworks where a journey from ordinary working conditions or the earth happens. Stress Corrosion Cracking can be constrained by the consolidating the measures given underneath: Choosing a material that isn't vulnerable to the administration environment Ensuring that any progressions to the earth brought about by cleaning are not negative to the material. Controlling the administration worries through cautious structure and limiting pressure fixations to keep them beneath the basic worth. Warmth Treatment lessens the remaining worries in the material and thusly diminishes the vulnerability to Stress Corrosion Cracking. Using consumption inhibitors during cleaning activities or to control the earth in a shut framework. Covering the material and successfully confining the material

I. Carbon Migration

Carbon relocation over the weld interface is viewed as a noteworthy factor in the "life" of a progress joint, since time subordinate property changes happen in the districts where carbon development occurs. The carbon movement causes loss of solidarity in the ferrite material contiguous the weld interface and an expansion in hardness (and presumably additionally in quality with an adjustment in the modulus of flexibility conceivable) in the filler metal (carbon-advanced zone). These zones are promptly nearby each other and give a huge change in properties over a tight district. Be that as it may, a few speculations can be expressed concerning carbon movement in a welded joint: Carbon relocation is legitimately subject to time, temperature and carbon substance of the base metals. Carbon diffuses five to multiple times quicker in ferrite than in austenite at a similar temperature. Warm anxieties following up on the weld interface upgrade carbon dispersion, in this manner the metals having bigger co-effective of warm extension like tempered steel will encounter progressively fast development of the carbon drained zone. The carbon drained zone displays low pliable and creep quality and decreased recrystallization temperature. In any case, the properties are not explicitly defined. The carbon-drained delicate zone is controlled by the harder and more grounded carbon-enhanced zone quickly neighboring during warm cycling. The advancement of an intricate pressure state including shear along the interface, in this way restraining uniform strain and will in general make misshapening in the delicate zone.

II. LITERATURE SURVEY

Over the years a lot of research has been done in the area of dissimilar welding and many interesting results have been brought up with regards to the problems encountered in dissimilar welding. With dissimilar welding finding its use in nuclear, petrochemical, electronics and several other industrial domains, this section brings into account the work of the predecessors in this field.

A. Research papers

Chengwu et al. [1] in their work on weld interface microstructure and mechanical properties of copper-steel disparate welding, the microstructure close to the interface between Cu plate and the intermixing zone was explored. Exploratory outcomes indicated that for the welded joint with high weakening proportion of copper, there was a progress zone with various filler particles close to the interface. However, if the weakening proportion of copper is low, the change zone is just created close to the upper side of the interface. [1] At the lower side of the interface, the fierce blasting conduct in the welding pool prompted the entrance of fluid metal into Cu. The welded joint with lower weakening proportion of copper in the combination zone showed higher pliable strength. Jiang and Guan [2] contemplated the warm pressure and remaining worry in disparate prepares. They recommended that enormous lingering stresses are initiated by welding in the weld metal and warmth influenced zone (HAZ), which superimpose and increment the warm stress. Gyun Na, Kim and Lim [3] considered the remaining pressure and its forecast for disparate welds at atomic plants utilizing Fuzzy Neural system models. The variables that have an effect upon exhaustion quality are lingering pressure, stress fixation, the mechanical properties of the material, and its smaller scale and full-scale structure. Yun Na et al. [3] expressed that leftover pressure is one of the most significant factors however its impact on high-cycle weakness is of more worry than different components. Remaining pressure is a pressure or pressure that exists in a material with no outer burden being applied, and the leftover worries in a segment or structure are brought about by inconsistent inside lasting strains. Welding, which is one of the most noteworthy reasons for lingering pressure, normally delivers enormous tractable anxieties, the greatest estimation of which is roughly equivalent to the yield quality of materials that are joined by lower compressive leftover worries in a part. [3] The remaining worry of welding can fundamentally hinder the exhibition and unwavering quality of welded structures.

The integrity of welded joints must be guaranteed against weariness or consumption during their long use in welded segments or structures. On stress erosion breaking Gyun Na et al. [3] expressed that pressure consumption splitting as a rule happens when the accompanying three elements exist simultaneously: helpless material, destructive condition, and malleable pressure including leftover pressure. Therefore, leftover pressure turns out to be exceptionally basic for stress-consumption breaking when it is hard to improve the material destructiveness of the parts and their condition under working conditions. Khan et al. [4] contemplated laser shaft welding of disparate hardened steels in a filet joint setup and during the investigation metallurgical examination of the weld interface was finished. Combination zone microstructures contained an assortment of complex austenite ferrite structures. Nearby miniaturized scale hardness of combination zone was more noteworthy than that of both base metals. The welding combination zone microstructure comprises of for the most part essential ferrite dendrites with a between dendritic layer of austenite. [4] This austenite frames through a peritectic–eutectic response and exists at the ferrite solidification limits toward the finish of solidification. Some lathy ferrite morphology is likewise seen in this zone. This is because of limited dispersion during ferrite– austenite change that outcomes in a remaining ferrite pattern. Khan et al. [4] arrived at the resolution that development of ferrite along the austenite grain limit in the warmth influenced zone on austenite side is watched. Simultaneously, microstructures are made out of two-stage ferrite and martensite with intra-granular carbide on ferrite side. Additionally the variety in nearby miniaturized scale hardness saw over the weld relies upon the portion intermix of each base metal and the redistribution of austenite-and ferrite-advancing components in the weld. Itoh et al. [5] got a patent on the joined structure on the divergent metallic materials. This creation relates for the most part to a joined structure of unique metallic materials having various qualities. All the more explicitly, the development identifies with a joined structure of a current conveying contact or curving contact which are utilized for, e.g., a force breaker, or a covering end structure of a metal base and a covering material for improving conductivity and warmth resistance. Delphin, Sattari-Far and Brickstad [6] contemplated the impact of warm and weld remaining weights on CTOD (Crack Tip Opening Displacement) in flexible plastic break examination. They expressed that structures may come up short on account of split development both in welds and in the warmth influenced zone (HAZ). The welding procedure itself actuates lingering worries in the weld and HAZ, which add to split growth. Delphin et al. [6] utilized a non-direct thermoplastic limited component model to reenact the circumferential weld in a generally dainty walled treated steel pipe. After the channel had chilled off in the wake of welding a circumferential surface break was presented. The break, situated in the focal point of the weld, was exposed to two kinds of loads. Right off the bat, the welded pipe was exposed to an essential pliable burden, and afterward to an auxiliary warm load. Delphin et al. [6] expressed that the decision of solidifying model is significant. It is accepted that kinematic solidifying is a superior decision than isotropic solidifying in low cycle reenactments for example in a couple pass welding process, as in the present study. For the instance of weld lingering worries in mix with high warm anxieties, it is discovered that the versatility initiated by the warm burdens isn't adequate to smother the impact of weld remaining weights on CTOD, in any event, for exceptionally high warm loads. The lingering stresses can be loose by emptying from an essential elastic load. Mai and Spowage [7] accomplished their work on characterisation of disparate joints of steel-kovar, copper-steel and aluminum-copper. It was expressed in their work that joining of divergent materials is one of the difficult undertakings confronting present day manufacturers. Dissimilar metal welding advances find application in numerous divisions, for example, miniaturized scale gadgets, clinical, optoelectronics and microsystems. [7] The small geometry of the joints and the distinctive optical and warm properties of the materials makes laser welding one of the most reasonable creation methods. Also high temperature inclinations in a welding may result in martensitic responses prompting unreasonable hardness in the combination zone. [7] The X-beam pressure investigation method couldn't resolve the pressure varieties produced by the diverse handling parameters utilized. In comparative steel welds the lingering worry at the focal point of the weld pool has been accounted for to be near the material yield strength. Colegrove et al. [8] considered the welding procedure sway on remaining pressure and twisting. Their work tries to comprehend the connection between heat input, combination territory, estimated contortion and the lingering pressure anticipated from a straightforward numerical model, and the remaining burdens is approved with test data. Residual stress is brought about by the compressive yielding that is happening around the liquid zone when the material is warmed and its extension during welding. [8] When the weld metal cools it gets contracted which results to an elastic lingering pressure, fundamentally in the longitudinal direction. After the welding is more than, a remaining malleable pressure is available over the weld centreline which causes an adjusting compressive pressure away from the weld zone. [8] The ductile remaining weight on the weld centreline diminishes the weakness quality and sturdiness, particularly when joined with any of the indents or different imperfections identified with the weld bead. The other primary finding of Colgrove et al. [8] is that the warmth information and mutilation go with one another in about a direct relationship. The outcomes got for the lingering pressure show that the width of the pinnacle ductile increments with heat input. At long last the leftover pressure estimations demonstrate how the pliable pinnacle augments up withincreasing the warmth input. There is a little contrast in the size of the pinnacle elastic for the distinctive welding processes. Arunkumar, Duraisamy and Manikandan [9] contemplated the mechanical properties of unique metal cylinder welded joints and named a portion of the alloying components that improve the weldability or the welded joint. Composite Steels, for example, that contain chromium and molybdenum. This organization conveys great weldability and high hardenability for the above expressed alloys. Chromium gives improved oxidation and consumption opposition. Also, molybdenum expands quality at raised temperature. [9] The mix of chromium and molybdenum additionally builds protection from high temperature hydrogen assault and to creep. Arunkumar et al. [9] likewise expressed that unnecessary entrance of a weld root can be amended by appropriate arrangement of cylinders in foundation of weld joint; concentric bore at closes, right welding current. Porosity in welded joint can be diminished by utilizing low hydrogen welding process, expanding protecting gas stream, expanding heat information and utilizing clean joint faces. Chung et al. [10] contemplated microstructure and stress erosion splitting conduct of the weld metal in unique welds and helplessness to push consumption breaking regarding pliability misfortune is reliant in expanding request of seriousness is; undiluted weld metal, the progress zone and the weld interface. This implies defenselessness to stretch erosion breaking is progressively identified with the instance of weak fractures. Chung et al. [10] expressed that interface splitting is frequently connected with a solidified interface locale in the weld, suggesting that the weld interface assumes a significant job in deciding SCC susceptibility. Chung et al. [10] likewise saw that the microstructures close to the weld interface are convoluted, comprising of martensite and carbides. Clearly, their quality caused between granular breaking and significantly decreased the SCC obstruction of the weld. Moreover, the basic intermittence at the interface additionally builds the SCC helplessness of the weld interface specimen. One of the significant deductions from the investigation of Chung et al. [10] was that the nearness of alloying components in the warmth influenced zone and combination zone differed with good ways from the weld interface, therefore, the SCC defenselessness changed in like manner. The more Ni and Cr substance, the less the example would be vulnerable to SCC. Lundin [11] did his examination on divergent welds with its accentuation on carbon movement, stress/strain condition of welds and change joint disappointment component. The examination expressed that most of disappointments have been related with austenitic hardened steel filler metal joints, and it is viewed as that the disappointment mode displayed by thenickel-based filler metals is on a very basic level not quite the same as that with the austenitic spotless fillers. Lundin [11]said that the splitting regularly starts at or close to the outside surface. The breaking results legitimately from void linkup, grain limit partition or tearing. It is commonly corresponding to the weld interface. The breaking is related with or exacerbated by oxidation-oxide indenting. The relative development coefficients of the different weld metal locales are critical as to warm pressure generation. Increasing the Ni substance of the filler metal adjusts carbon dissolvability, makes carbides less steady, changes diffusivity and when all is said in done retards carbon relocation from the ferritic material. [11] The impact of time, temperature and material structure impacts the nickel rich weld metals diminishes carbon relocation. Further, the utilization of balancing out components in the ferritic part is successful in combatting relocation however neither so effectively with nickel is the chief alloying components

III. PROBLEM FORMULATION

The point of this exploration venture has been to contemplate disparate metal joint utilizing a filler metal. Different welding is utilized to manufacture the weight vessels and funneling in power plant however disappointments happen regularly due to:

1) Thermal Stress which is created because of distinction in co-effective of warm development.
2) Difference in mechanical properties, the neighborhood warming and ensuing cooling brings about huge lingering stress. This warm pressure superimposed on weld remaining pressure and working pliable pressure advances fragile break, increment weakness to exhaustion and stress consumption splitting during its administration life. The area of this exploration covers cause, impact and disposal of issues caused because of stresses, carbon relocation and stress erosion cracking. The metals to be welded are 304 tempered steel and 1020 plain carbon steel and the filler metal utilized is 302 Stainless steel whose properties has been taken like 304 hardened steel with the end goal of analysis. The welding process has been reproduced utilizing limited component investigation. The product utilized for this examination is ANSYS 13.0 utilizing its Workbench module. It is on the grounds that Workbench is an exceptionally amazing asset to reproduce a welding joint and induce the outcomes. Additionally it has a notoriety of thinking of results near the down to earth esteems. The info parameters are handily taken care of and limit conditions, reproduction programs and geometrical demonstrating is advantageous because of its easy to use realistic interface.

A. Input Parameters

The input parameters in this analysis are the thermo-mechanical properties of the materials getting into the welding joint. All the properties used in this analysis are temperature dependent.

1) Composition

The composition of the metals used in this simulation of welding joint is given below:

1) 304 Stainless Steel

The composition of 304 stainless steel is shown in table 1. Chromium along

Table 1: *Composition of 304 Stainless Steel*

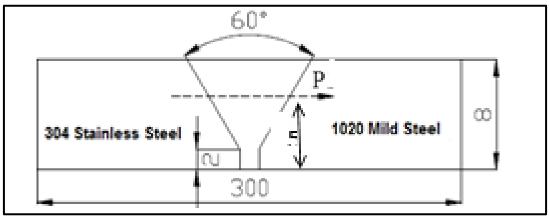
Fe	C	Si	Mn	S	P	Cr	Ni
71.433	0.058	0.35	1.32	0.007	0.032	18.52	8.28

2) 1020 Mild Steel

In plain carbon steel, carbon is the principle alloying element. Composition of 1020 mild steel is shown in table

Table 2: *Composition of 1020 Mild Steel*

Fe	C	Mn	P	S
99.31	0.2	0.4	0.04	0.05



3) 302 Stainless Steel

The composition of 302 stainless steel is almost similar to that of 304 stainless steel and the composition has been taken same for the purpose of analysis. 302 stainless steel has been used as the weld metal in the first analysis and subsequently replaced by Inconel 625 in the second analysis.

4) Inconel 625

Inconel 625 is a non-magnetic, corrosion and oxidation resistant, nickel-based alloy. This alloy has high fatigue strength, exhibits excellent resistance to stress corrosion cracking. Nickel and Chromium provide stabilizing effect from oxidizing environments. The nickel-based alloys like Inconel also resist problems caused due to carbon migration. Pitting and crevice corrosion are prevented by Molybdenum stabilizes the alloy against sensitization during welding. Due to these properties, Inconel is widely used in dissimilar welding. The composition of Inconel 625 which has been used in this analysis has been shown in Table 3

Table 3: *Composition of Inconel 625*

Ni	Cr	Mo	Fe	Mn	C	Cu	Si
61.5	23.0	8.0	6.5	0.25	0.08	0.2	0.25

2) Mechanical Properties

The mechanical properties that have been chosen for the purpose of analysis are density, Poisson's ratio, modulus of elasticity and yield strength. The mechanical and thermal properties of the materials used in this analysis have been extrapolated from the graph published by Jiang and Guan [2] in their study on residual stress in a welded joint.

1) 304 Stainless Steel

The mechanical properties of 304 stainless steel that have been used in this analysis have been given in table 4

3) Thermal Properties

The thermal properties of the materials that were necessary for this analysis were melting point, thermal conductivity, specific heat and co-efficient of thermal expansion.

1) 304 Stainless Steel

The thermal properties of 304 stainless steel that have been used in this analysis have been given in table 7. The melting point of 304 stainless steel is taken as 14270C

Table 7: *Thermal Properties of 304 Stainless Steel*

Variation of properties with temperature	Thermal Conductivity (W/m^{0}C)	Specific Heat (J/Kg^{0}C)	Thermal Expansion Coefficient ($^0C^{-1}$) * 10^{-5}
0 ^{0}C	15	501	1.8
200 ^{0}C	18	530	1.9
400 ^{0}C	21	580	2.0
600 ^{0}C	26	620	2.05
800 ^{0}C	34	650	2.1
1000 ^{0}C	36	680	2.15
1200 ^{0}C	36	690	2.2
1400 ^{0}C	36.1	700	2.25
1600 ^{0}C	36.1	705	2.29

2) 1020 Mild Steel

The thermal properties of 1020mild steel that have been used in this analysis have been given in table 8. The melting point of 1020 Mild Steel has been taken as 15150C.

3) Inconel 625

The thermal properties of Inconel that have been used in this analysis have been given in table 9. The melting point of Inconel 625 is taken as 14040C for cooling of the parts after the welding is over the convective heat transfer co-efficient has been taken as 15 W/m2 0C. The ambient air temperature has been taken equal to 27 0C.

B. Finite Element Analysis

Finite element analysis has been done in the case of this welding to predict stresses, susceptibility to stress corrosion cracking and the location where failure is most likely to occur. Some of the other methods of analysis were not used due to the following given reasons:

1) Accurate measurement of stresses is very difficult using conventional testing techniques.
2) X-ray method can be used for analysis but it is capable of giving only surface stresses.
3) Neutron Diffraction Method can give the through thickness stress but not the stress distribution.

So, this is the reason why finite element analysis has been used because it is capable of predicting highest risk zone and the stress distribution throughout the parent metals, heat affected zone and the weld metal.

C. Problem Statement

The problems which have been analysed in this research are three. First aspect is reduction in stresses developed, second is minimization of carbon migration and the third is decreasing the susceptibility to Stress Corrosion Cracking. Considering the above objectives two metal plates, equal in size with a dimension of 300 x 150 x 8 mm are butt welded with filler between them. The parent metal plates are of 304 stainless steel and 1020 mild steel material. The welding arrangement .The welding simulation has been done firstly by studying the welding temperature field followed by incrementally applying the temperature results to simulate the weld. After the welding process is over residual stresses get developed inside the welded parts. This welded part when kept under operating conditions which are taken as high as 600 0C, results in development of thermal stresses inside the welded part.

The analysis has been done considering three models. Model A is analysed only for thermal stresses and the results are inferred. Model B is analysed only for residual stresses and the results are inferred. Model C is analysed for thermal stresses superimposed with residual stresses. That means mathematically-Model A + Model B = Model C. And all the results are taken along the line of length 30mm which lies 5mm above the weld root. Now in the second case, the weld metal A302 Stainless Steel is changed to Inconel 625 and then again the thermal, residual and thermal stress superimposed on residual stresses are calculated.

D. Assumptions and Conditions

1) Heat flow inside the welded parts is assumed to be by conduction using the fundamental equation of conduction as given in equation (i);

$$k\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)+Q_{int}=\rho c\frac{\partial T}{\partial t} \quad \text{(i)}$$

where k is the thermal conductivity, T is the transient temperature field which is a function of time t and Cartesian co-ordinates (x, y, z) with Q as internal heat source rate, ρ as density and c as specific heat capacity.

2) Heat loss from the welded part to the ambient air is assumed to occur by convection following the governing equation of cooling(ii);

$$= -hA(Ts - Ta) \quad \text{(ii)}$$

, where Qc is the rate of cooling, h is the convection co-efficient taken here 15 W/m2 oC for all the cases, Ts is the surface temperature and Ta is the temperature of ambient air taken 27 oC.

3) Thermal stress is calculated from the start up at 27 oC to 600 oC. Thermal stress simulated in the welding using its global modelling matrix reduced to give thermal stress at any two nodes is given in equation (iii);

$$\begin{bmatrix} -E\alpha T \\ -E\alpha T \\ 0 \end{bmatrix} = \frac{AE}{L}\begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ 0 & 0 & 0 \end{bmatrix}\begin{bmatrix} d_1 \\ d_2 \\ d_3 \end{bmatrix} \quad \text{(iii)}$$

, where E is the Young's Modulus of Elasticity, T is the transient temperature field, α is the co-efficient of thermal expansion, A is the cross sectional area, L is the length of the section and (d1, d2, d3) are the nodal displacements caused due to temperature load at any three nodes.

However displacement boundary condition d1=0 is taken to avoid rank deficiency. In this case of modelling the welded part is assumed to be fixed normal to the weld.

4) For residual stress analysis the elements are activated and deactivated by element birth and death technique. This means that after a weld pass is over on an element, after solidification the element gets structurally activated.The material properties are set to zero for the deactivated elements. The welding has been carried out at 1500 oC. Therefore, the initial condition for an element after reactivation is its melting point. When an element gets reactivated i.e. born then its mass, element load, etc. are set to their original values.

IV. Results and Discussion

The results that are obtained after the weld simulation can be taken considering two cases. In the first case 302 stainless steel has been taken as the weld filler metal whose properties are taken the same as 304 stainless steel which is one of the parent metals. So the results inferred from all the three models viz. A, B and C which will be taken one by one.

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