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RESEARCH ARTICLE

Effect of Gradual Variation of Metal Composition on Stresses Generated in Weld Interfaces

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ABSTRACT

Dissimilar metal joints formed by conventional welding creates residual stress at the interface and leads to an earlier failure than expected. The conventional methods are rapidly being replaced by advanced techniques, such as transition layer grading. This kind of transition grading aims to form the welding component akin to functionally graded material. The present paper aims to analyze different stress concentration conditions by varying temperatures, loads, and the number of transition layers. The material in the weld zone varied linearly when the number of layers was increased, which is analogous to functionally graded materials. The finite element model of a dissimilar metal welded pipe was simulated using ANSYS Workbench 14.5. Based on the executed simulations, it was observed that residual stress at the weld interface decreased as the number of layers increased up to a certain critical number of graded layers. Furthermore, negligible effect on stress reduction has been observed beyond this critical number of graded layers.

Keywords: Transition grading, Welding, Stress reduction, FEA

1. Introduction

Welding is a common process of joining two or more metals and the difference in the properties of joining metals plays significant role on the strength of joints. The difference in material properties such as Coefficient of Thermal Expansion (CTE), modulus of elasticity (E), Poisson's ratio combined with the joint geometry leads to stress concentration in the joint interface [1]. Also, the formation of the residual stress/strain and the induced distortions in pipe joints is another concern. In high temperature applications, each side of the joint tends to expand at a different rate due to differences in CTE, E, Poisson's ratio, as well as geometry. This results in very high stresses being developed in the dissimilar metal joints (DMJ). These high stresses can be avoided by using a suitable filler material in the welding process. The filler material is selected in such a way that the material properties lie roughly between the base metals. The difference between composition and related properties can be minimized using proper filler materials. The use of filler materials increases service life of components. But it is seen that relatively high stresses are still present at the interface [2]. These stress concentrations combined with thermal cycling and high temperatures cause creep failure in the joints after a predictably shorter time than the rest of the system. The difference in tool geometry and welding parameters induces significant changes in material flow path during welding as well as in the microstructure in the weld zone [3]. In addition, the formation of cracks in the heat affected zone (HAZ) is also a prime concern. The cracks are formed due to formation of the brittle intermetallic compound at the joint interface [4]. The solid solubility is essential for obtaining good quality dissimilar metal welds. The difference in melting points of the base metals is also a significant problem as one of the one base metal melts earlier than other. Often one metal melts much faster than the other one and hence they do not complete mix. This results in joints of poor quality having insufficient strength. The high thermal conductivity metals such as Copper when joined with steel dissipates the heat away from weld and causes difficulty in reaching the melting temperature [5]. The melted copper penetrates the grain boundaries of stainless steel and form cracks at HAZ. It was observed that disimilar metal weld (DMW) joints are susceptible to hydrogen embitterment in chloride solutions at room temperature [6]. It has been conclusively proved that in DMW of stainless steel and non-stainless steel, the failure load of cross tension specimen was around 75% of the lap shear specimens. Another research has concluded that the difference in grain structure may cause early failure of weld due to uneven stresses [7]. One of the major problems in metal inert gas (MIG) welding is mixing of metals in DMW [8]. Jang et al. [9] carried out tensile tests on dissimilar metal welds between low alloy steel and 316 stainless steel. They also conducted micro hardness tests to measure the variation in strength along the thickness of the weld. They reported that the strength was much greater at bottom of the weld than the top of weld. Some more researches conducted on dissimilar metal welds [10] using gas tungsten arc welding process observed that at the dissimilar metal joint interfaces cracks were developed. Some other researchers reported a similar phenomenon while working on 214 Cr-1 Mo steel and Type 316 stainless [11]. It was observed the relative effectiveness of Mn and Ni in stabilizing weld metal austenite varies with Cr content. They developed an empirical equation to describe the variation in the austenite stabilization. An in-depth analysis on the mechanical behaviour of a friction stir welded joint of aluminium alloy was conducted by Dilip et al [12].

The present paper contains a brief introduction of welding focusing its use in dissimilar metal joints followed by the common issues in such joints formed by conventional welding. Section 2: Materials and Methods proposes a Weld joint of a pipe specimen by unconventional welding/joining process- Transition graded metal joint with the help of LENS (laser engineered net shaping). The finite modelling and analysis of DMJ is carried out by using an industry baseline model and is simulated for several parametric conditions to analyse the stress distribution. The results obtained are discussed for different number of layers used in grading and for varying tensile load conditions and temperature. Abrupt change in elastic properties of material, change in poison's ratio, coefficient of thermal expansion and the uneven geometry are the prime reasons of stress concentration in weld interfaces [13]. In the current paper, dissimilar metal welds in pipes made of stainless steel and carbon steel are considered. Stainless steel having higher thermal expansion rate than the carbon steel tries to expand more and hence is the main reason behind the generation of high concentration in the weld zone. The fact that at the interface the material properties- primarily the modulus of elasticity and Poisson's ratio vary abruptly further increase this stress concentration. Hence, efforts have been made by various researchers [14] [15] [16] to gradually vary the material properties in weld interface such that the variation in material properties at the weld zone is continuous rather than being abrupt. In past, various researchers have used FEA to make predictions about different welding parameters. Dhas, et al. [17] developed a FEM model to correlate the temperature and residual stresses on the weld zone. Similarly, Jayakumar et al. [18] used a 2D FE model to predict residual stress in austenitic stainless steel. A more detailed literature on friction stir welding may be found in works of Chaudhari et al. [19].

2. Materials and Methods

In the current research the feasibility of using transition grading technique to reduce the stress concentration in the weld zone is explored. ANSYS Workbench 14.5 has been used to simulate the DMJs in which material composition and their properties are varying along with the length of the weld. ANSYS Workbench is a general-purpose Finite element software [20] [21]. The solutions are dependent on the type mesh used [22] [23] [24]. Before solving any model my FEM software, it is important to perform a mesh convergence study [25] [26] [27]. A typical application of dissimilar metal welded pipes used in nuclear reactors is simulated. The CAD model as shown in Figure 1 is generated and is used to carry out the stress analysis.

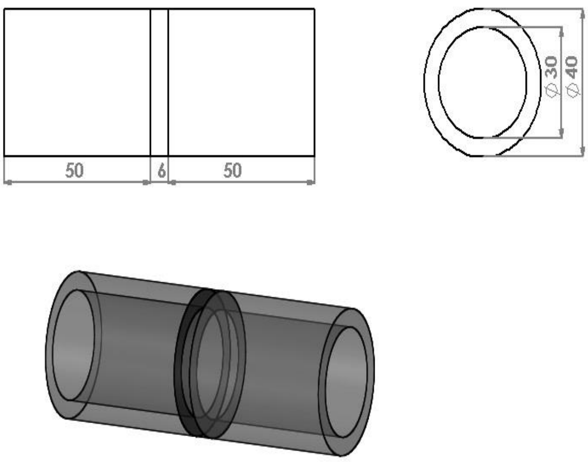

Figure 1: *CAD model of the dissimilar metal welded pipe.*

The model is capable of handling changes in parameters such as joint shape, size, material properties and the number of layers. The material properties considered are shown in the Table 1. The two pipes made of different materials- (Material 1: Chrome moly alloy and Material 2: Stainless steel alloy) are welded by depositing layers of varying compositions which ensure gradual variation in material properties. The number of layers in the weld zone is increased in each successive simulation to study the effect on stress concentration in the interface. Three models consisting 20, 40 and 60 number of layers i.e. each weld bead thickness of 0.3 mm, 0.15 mm and 0.1 mm respectively is considered. Two loading condition are considered. In the first case, tensile pull is applied at pipe ends, and in second case compressive load is applied. The simulations are carried out at room temperature (25°C) and at elevated temperature (500°C) for 20kN, 35kN and 50kN loads.

Table 1: *Material properties of the two base pipes.*

Materials	% Carbon	E (GPa)	ν	CTE (°C)
Material 1: Chrome moly alloy	0.108	210	0.28	12.9 x 10^{-6}
Material 2: Stainless steel alloy	0.08	193	0.29	17.3 x 10^{-6}

3. Results and Discussion

In the simulated model, material is attributed as stepwise linear. The rationale behind selecting three different numbers of layers- 20, 40 and 60 is that by increasing the number of layers the material distribution in the weld zone can be assumed to be continuously linear rather than being stepwise. The width of each layer is 0.3, 0.15 and 0.1 mm respectively.

Table 2: *Maximum equivalent stress (in MPa) at different layers under tensile loading*

No of layers	**20**		**40**		**60**	
Load (kN)	25 °C	500 °C	25 °C	500 °C	25 °C	500 °C
20	49.65	1449.7	42.43	1502.2	42.34	1489
35	85.1	1450.6	74.38	1503.5	74.34	1490
50	120.55	1451.6	106.34	1504.9	106.14	1491

Table 2 contains the simulated maximum Von Mises stress in the weld zone at room temperature under tensile load of 20, 35 and 50 kN. It is seen that as the number of layers increases the stress decrease. However, the reduction in stress is much more in between 20 to 40 layers as compared to 40 to 60 layers. The effect of high temperature on the stresses developed at the dissimilar metal interface is reported in Table 2. While keeping all other parameter same the environment temperature in increased to 500 °C. This is done to simulate the pipes used in nuclear reactors carrying superheated steam. It is observed that at elevated temperature the increase in layers in the weld interface does not have desired effect in reducing stress. In fact, the stress in the interface increases from 20 to 40 layers and then decreases marginally from 40 to 60 layers. Interestingly it is observed that the increasing loads have negligible effect at elevated temperature.

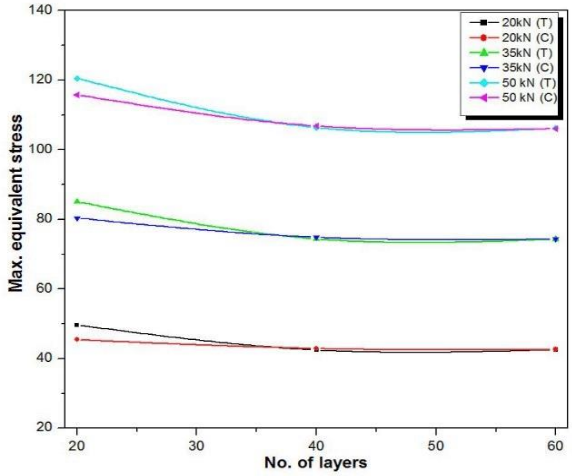

Figure 2: *Max. Stress vs. number of layers at room temperature.*

Figure 2 shows the variation of stresses at room temperature. It is seen that irrespective of the loading condition as the number of layers is increased, the induced stress becomes lesser.

Table 3: *Maximum equivalent stress (in MPa) at different layers under compressive loading*

No of layers	20		40		60	
Load (kN)	25 °C	500 °C	25 °C	500 °C	25 °C	500 °C
20	45.41	1447.3	42.882	1498.9	42.623	1485.8
35	80.378	1446.6	74.828	1497.9	74.317	1484.7
50	115.83	1445.8	106.78	1496.5	106.02	1483.5

Table 3 shows the maximum von misses stress at 25 °C and 500 °C under compressive loads. The nature of stress reduction observed is same as in the tensile loading condition. As expected the maximum stress in the weld zone under compressive load is lower than tensile loads. Figure 3 shows that the stress increases as layers are increased from 20 to 40 layers and then reduces after increasing the layers to 60.

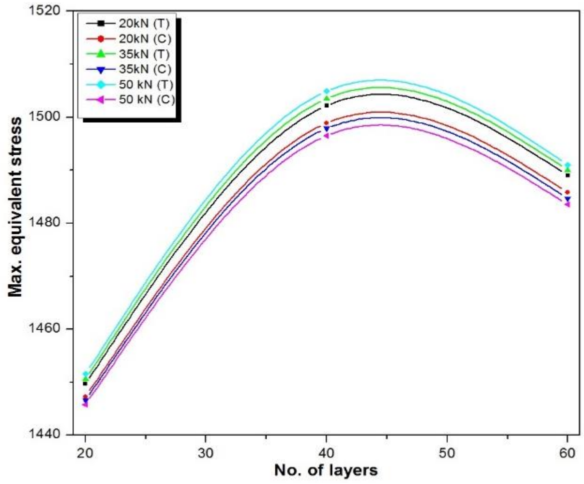

Figure 3: *Max. Stress vs. number of layers at elevated temperature.*

4. Conclusions

Stress analysis of dissimilar metal welds formed by using transition grading technique is conducted using finite element method (FEM). The developed FEM model are efficient. It is observed that about 12-15% reduction in residual stress is observed in the weld zone for dissimilar metal welded pipes under tensile load at room temperature. The reduction in residual stress is much more significant for transition from 20 to 40 as compared to 40 to 60 layers. At elevated temperature, negligible effect of transition grading scheme is seen. In general, the residual stress generated in tensile load condition are more than those under compressive loading.

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