REVIEW OF WELDING DEFECTS AND NDT METHODS IN WELDING OF STAINLESS STEEL 316SS AND 16MNCR5

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ABSTRACT

Amongst the various materials that exhibit capabilities to meet high strength at elevated temperatures, corrosion resistance, toughness at cryogenic temperatures, ease of fabrication, etc stainless steels fulfill all of the above design criteria. Thus, we find application of stainless steel in wide range of industrial, commercial and consumer applications in demanding conditions in the chemical process industry and at the same time comparatively delicate conditions in the pharmaceutical and food industry. Stainless steels offer a good fabrication economy along with optimal strength and corrosion resistance. During the welding process variety of defects such as porosity, blow holes, undercut, weld crack, incomplete fusion, slag inclusion, incomplete penetration, spatter, distortion, hot tear, etc. are observed. At the same time the quality of weld can be assessed by measurement of the weld penetration depth, hardened weld boundary, and inspecting the formation of porosity. Although majority of the current methods associate to destruction of the specimen, it is also found that the non-destructive assessment is also possible through various NDT quality check methods.

The paper focuses on the classification, identification, causes, remedies of the weld defects, review of the non-destructive methods recently researched. The knowledge of the above will be used in optimal process selection, and NDT quality check methods in future work that will be carried out for the analysis of welding joint by different welding process of Stainless steel 316SS and 16MnCr5

Keyword: *Stainless steel, weld defects, NDT, Analysis of welding joints, Welding process*

1. INTRODUCTION

Stainless steels are basically alloys of iron that have a minimal chromium of 10.5 % with or without addition of other alloying elements such as manganese, nickel, silicon, niobium, boron, aluminum, cobalt, molybdenum, copper etc, the addition of the chromium serves the purpose to develop the corrosion resistance ability of the steel as it leads to form a passive film of chromium oxide, that is the reason why most stainless steels contain higher amounts of chromium.

1.1 Classification of Stainless Steels

Stainless steels are categorized into different categories based on their metallurgical structures, as shown below:

- Austenitic stainless steels

- Ferritic stainless steels
- Matensitic stainless steels
- Duplex stainless steels

In general, the nature of the martensitic stainless steel and the ferritic stainless steel is free from nickel, where as the austenitic stainless is the use of nickel and chromium as the alloying elements. The duplex stainless steels use in suitable proportions of nickel and chromium as the alloying elements to attain a structure that is mix of austenite and ferrite stainless steel.

1.2 Welding characteristic of Stainless Steels

The characteristic of welding especially to different stainless steel are discussed below:

1.2.a Austenitic stainless steels

Owing to their face-centered cubic structure the Austenitic stainless steels offer high toughness in their welded structures at the same time are relatively easy to weld but their weld ability is a function of the amount of carbon contents. Grade 316 stainless steel shows low susceptibility to carbide precipitation and are weld able without corrosion only that they are used below 425^0C temperature to avoid sensitivity.

1.2.b Ferritic stainless steels

The ferritic stainless steels pose certain difficulties such as the rapid grain coarsening at elevated temperature of 950^0C and are found to be sensitive to slight change in chemical composition that have effect on corrosion resistance, ductility and toughness in a deleterious manner which can be rectified to some extent using process of annealing in post weld to relieve internal stresses.

1.2.c Martensitic stainless steels

The matenitic stainless are more difficult to weld than the ferritic and austenitic steels major reason being the structure transformation after welding resulting in changes like rise of cracks, change in volume, hardness etc., a remedy proposed is pre-heating before welding. As the matensitic structure is prone to hardness and brittleness the welding may be carried out in the annealed condition, some post heat treatments are always required after welding.

1.3 Welding processes of Stainless Steels

Stainless steels are often welded using fusion or resistance welding techniques.

Fusion welding entails a variety of procedures.

- Shielded Metal Arc Welding (SMAW)
- Gas Tungsten Arc Welding (GTAW)
- Submerged Arc Welding (SAW)
- Plasma Arc Welding (PAW)
- Electron Beam Welding (EBW)
- Laser Beam Welding (LBW)

2. WELD DEFECTS

A good or a sound weld is generally is characterized by analogous material characteristics of base material and should be free from crack, undercut, incomplete fusion, poor penetration, porosity, stag inclusion, improper alignment, spatter etc and weld defects are result of the incorrect welding process or the application of the incorrect welding procedure

2.1 Types of weld defects

- Porosity and Blowholes
- Undercut
- Weld crack
- Incomplete fusion
- Slag inclusion
- Incomplete penetration
- Spatter
- Distortion
- Hot Tear

2.1.a Porosity and blow holes

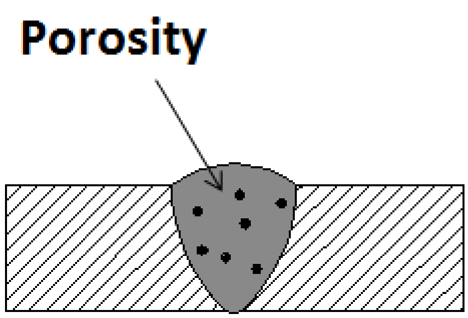

Figure 2.1.a: Porosity defect in welds

Porosity results as an effect of trapped gases, while combination of small bubbles is termed as porosity where as large concealed bubbles are termed as blow holes

Cause of Porosity / Blow holes	1. The joint has not been adequately cleansed. 2. Inadequate electrode selection 3. a soiled base metal a filthy road 4. Insufficient protection 5. Welding speed that is too fast 6. Weld amperage that is too high

Table 2.1.a: Porosity defect in welds

2.1.b Undercutting

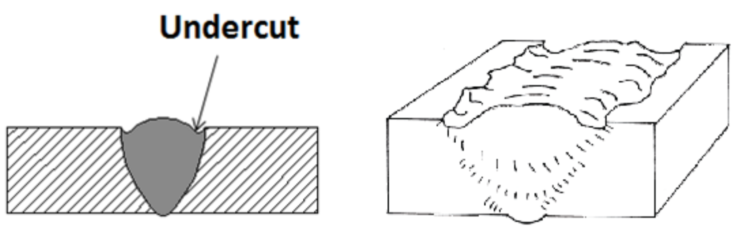

Figure 2.1.b.1: Undercut defect in welds

This defect results in reduced cross-section of the weld area in the form of grooves in the weld toe resulting in reduced strength of the joint.

Cause of undercutting	1. Working with a torch at an incorrect angle 2. Incorrect filler rod size or application 3. Welding too quickly 4. An excessive amount of amperage

Table 2.1.b.1 Undercut defect in welds

The undercut defects specific to the laser beam welding process are shown below

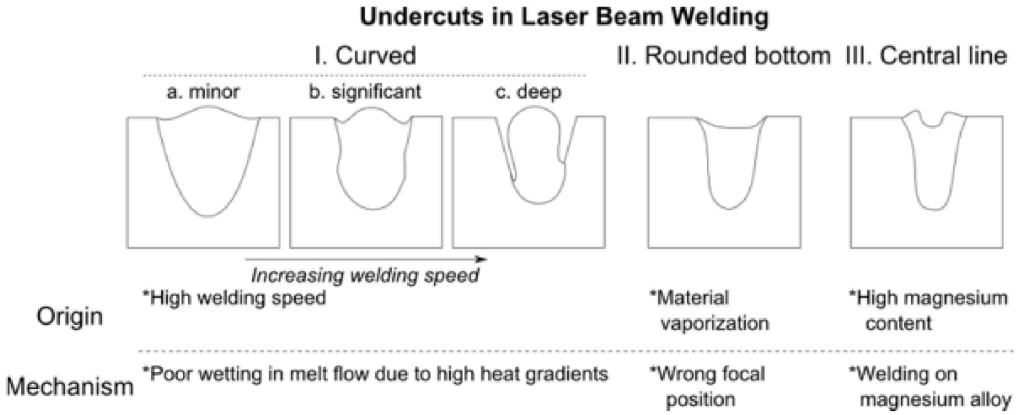

Figure 2.1.b.2: Types of undercuts specific to the laser beam welding process

2.1.c Welding cracks

By far the welding cracks are considered to be the most harmful of weld defects and hence are practically impermissible in any production process

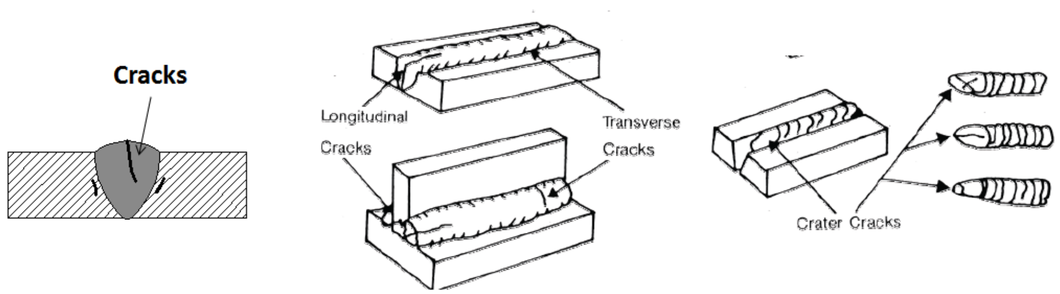

Figure 2.1.c: Welding cracks

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Cause of weld cracking	1. Incorrect filer rod selection 2. Excessive base metal dilution of the filler rod 3. Weld joint cooling too quickly 4. Joints with a lot of tension 5. Craters that haven't been filled 6. Picking the wrong filler wire 7. Beads are excessively tiny 8. Plate quality is poor 9. Base metal cooling in a short time

Table 2.1.c: Welding cracks

2.1.d Incomplete Fusion

Incomplete fusion defects result due to inappropriate fusion between base material and weld filler material that shows up between nearby weld beads resulting into an unfilled gap between the beads.

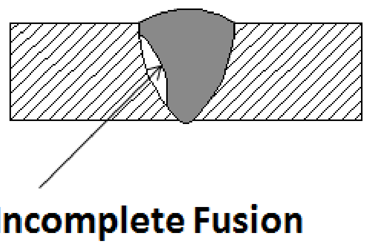

Figure 2.1.d: In complete fusion defect in welds

Cause of incomplete fusion	1. Fields of magnetism in the weld junction 2. A bad current adjustment 3. Defective electrodes 4. Electrode held at an incorrect angle 5. Electrode manipulation that isn't up to snuff

Table 2.1.c: Welding cracks

2.1.e Slag inclusion

Welding processes like the flux core arc welding, stick welding, submerged arc welding show defects of slag inclusion where in flux is seen to get stuck or included in the weld region's surface reducing the strength of joint and making t weaker often noticed to be located between adjacent weld beads i.e., in the unfilled gap between weld beads

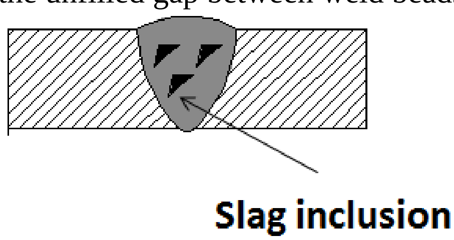

Figure 2.1.e: Slag inclusion defect in welds

Cause of slag inclusion	1. An overabundance of current in respect to pressure 2. A foreign substance on the surface 3. Electrode conductivity is insufficient electrically and thermally.

Table 2.1.e: Slag inclusion defect in welds

2.1.f Incomplete penetration

Incomplete penetration can be described as the groove not completely filled to its fullest extent, i.e., the distance highest surface of base metal and maximum extent of weld nugget is not reached resulting in the nugget void.

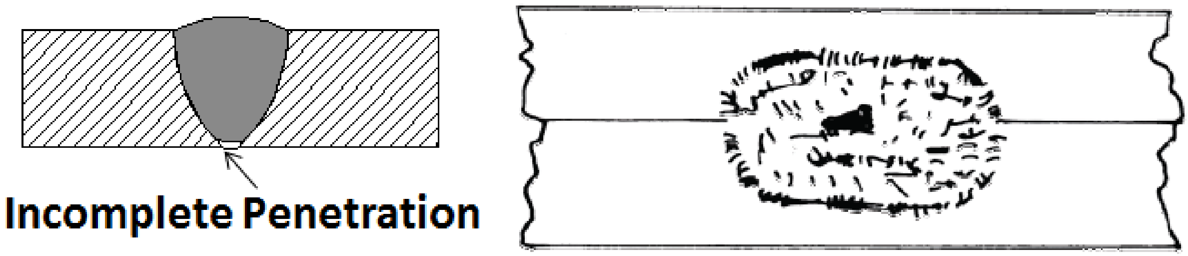

Figure 2.1.e: Incomplete penetration defect in welds

Cause of Incomplete penetration	1. Inadequate current 2. Insufficient weld time 3. Excess electrode force 4. Excessive weld time and current 5. Electrode dressing is flat 6. Inadequate hold time

Table 2.1.e: Incomplete penetration defect in welds

2.1.g Spatter

Commonly observed during gas metal arc welding, tiny metal particles ejected from welding arc that get deposited on base metal along the weld length throughout the weld beads termed as weld spatter.

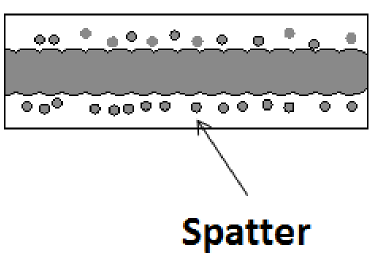

Figure 2.1.g: Spatter defect in welds

Cause of Spatter	1. Use of straight CO2 2. Voltage too low and/or current too high 3. Raised induction and/or slope 4. Increase the distance between the nozzle and the work surface.

Table 2.1.g: Spatter defect in welds

2.1.h Distortion

Due to the temperature grade existing at various sites along the weld joints, distortion is the variation in size and location between the positions of the two metal plates before and after welding. Or, to put it another way, the distortion is caused by the unequal extension and reduction of the weld metal, and that all types of distortion increase as the number of metal depositions increases [10].

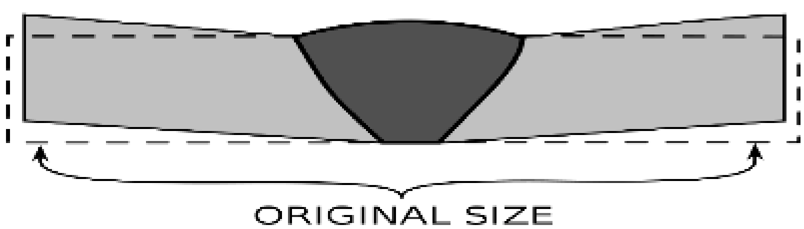

Figure 2.1.g: Distortion defect in welds

Cause of Distortion	1. Incorrect welding orders were used as a cause 2. Using a huge number of passes with electrodes of modest diameter. 3. Due of arc travel's modest pace

Table 2.1.g: Distortion defect in welds

2.1.i Hot tear

When the deposited metal after weld develops cracks in the nearby weld edges that propagate to increase in large size cracks that results as result of tearing of grain boundaries and normally occurs when the weld joint enters the plastic condition and therefore termed as solidification cracking (15)

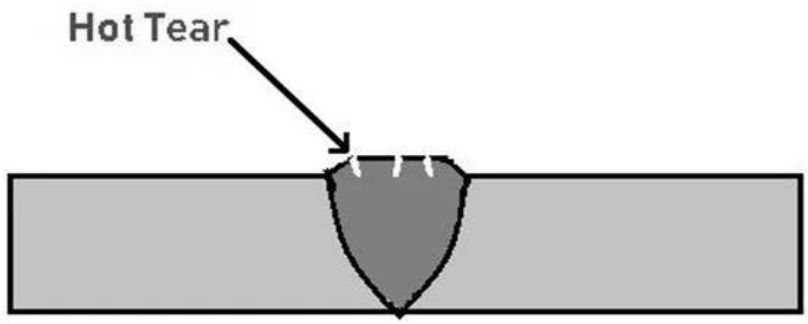

Figure 2.1.g: Distortion defect in welds

Cause of Hot tear	1. An excessive amount of current and welding time 2. Insufficient electrode force 3. An electrode dressing that is overly flat. 4. Inadequate hold time 5. Contraction due to heat

Table 2.1.g: Distortion defect in welds

3. PRECAUTIONS AND REMEDIES TO AVOID WELD DEFECTS

1. Selection of materials to be welded and appropriate electrodes that confirm to the specifications and standards are determines the good quality welds.
2. For a sound and strong weld, the proper joint design selection is absolutely necessary and also effective and easy slag removal should also be done.
3. To avoid poor penetration and to avoid development of slag pockets the proper bead formation is essential
4. Moisture on both the stainless-steel base metal and the filler material is detrimental to joint quality and hence appropriate drying is necessary to avoid moisture entrapment.
5. Cleaning of the base metal to make it free from dirt, dust, grease, varnish, oil etc. to avoid contamination is necessary as majority of the above materials are ready source of carbon during welding process.
6. Cleaning of the welded joint thoroughly during multi-pass welds is a key to strong welds, with special attention given to slag removal
7. Electrode sticking, interference of slag, excessive spatter results due to low current, appropriate current levels result in good quality joints.
8. Cracks, distortion, undercutting and corrosion as a result of chromium loss takes place at too high current values, so again optimal amperage should be selected

9. Using chill bars or back-up bars of copper is advised due to their high thermal conductivity, their application assures smooth welds metal surface and prevents the excessive base metal heating and avoids thermal distortion

4. INSPECTION OF WELDED JOINTS

The general quality of welds is examined by various methods prominently the non-destructive test is as discussed below:

4.1 Visual Inspection

As the most in-expensive but effective method using tools like weld viewers, magnification glasses, measuring scales, weld gages etc is termed as visual inspection that gives good indicators of weld quality and defects such as dimensional inaccuracy, cracks, spatter, undercut, bead size, incomplete fusion, distortion etc and hence it is the only examination method for commercial welds.

4.2 Non-destructive tests

The other commonly used non-destructive test are listed below
- Magnetic particles test
- Dye penetrant test
- Ultrasonic test
- Radiographic test

4.2.1 Magnetic particle test

This test is effectively used in ferromagnetic materials to detect weld defects such as cracks, porosity, slag inclusion, lack of fusion etc as the most reliable methods especially for surface discontinuities. The method used is to apply a thin coat of liquid solution-colored magnetic particles and then subjecting the work-piece to strong magnetic field, when magnetic field is removed the detection of flaws is characterized by concentration of magnetic particles

4.2.2 Dye penetrant test

The dye penetrant test uses colored dyes that may also be fluorescent that are sprayed on the welded surface, after excess dye removed using cleaner the flaws are detected and distinguished after drying. The method is popular due to its low cost and suitability to both magnetic and non-magnetic base metals, only limitation being that its application is suitable to surface flaws.

4.2.3 Ultrasonic Test

This method uses ultrasonic waves of short pulses that are reflected and the echo is a measure of the defects that can be observed on the CRT screen, the advantage being the location and size of the flaw or defect is measurable.

The advantages offered by the ultrasonic test are:
- Minute cracks can be detected because of high sensitivity.
- Section with relative high thickness can be tested due to high penetration ability
- Flaw size and location can be accurately determined,

4.2.4 Radiographic test

This method encompasses the sub-surface and internal weld defects by use of x-ray and gamma rays, especially that it can be recorded on film that gives nature and dimension of the weld flaws.

4.3 Destructive test

- Chemical analysis
- Tensile test
- Bend test
- Hardness test
- Impact test
- Macroscopic and microscopic examination
- Corrosion test
- Leak test
- Peel test

4.4 Review of recent trends in non-destructive test

Vijay Gohel et al (21) The authors developed a thermo-mechanical simulation of butt joint in stainless steel (SS 304) done using gas tungsten gas arc welding (GTAW) in Ansys workbench and validation was done using thermocouple records of actual process data.

Alaknanda Ashok et al (22) Radiographic images considering morphological aspects of image for incomplete penetration flaws through histogram equalization and noise filtering was done to develop a finally processed image, obtained by superimposing the segmented image over the original enhanced image to establish another method of non-destructive testing.

Xin Tang et al (23) The authors use machine vision for acquiring images in real time and analyze related features to evaluate the quality of laser welding to reduce the cost and time in later inspection.

5. CONCLUSIONS

Stainless steels offer a good fabrication economy along with optimal strength and corrosion resistance. Stainless steel find application in wide range of industrial, commercial and consumer applications in demanding conditions in the chemical process industry and at the same time comparatively delicate conditions in the pharmaceutical and food industry. The paper discussed the classification of stainless steels, various welding characteristics of these steel, the various welding processes suitable to these stainless steels, elaborate discussion on the various defects and the causes of these defects is done along with the precautions and remedies to avoid these defects is also presented in the paper. The various inspection methods have been discussed and finally the new methods of non-destructive testing such as thermo-simulation, radiographic imaging and real time image acquisition techniques are also discussed.

The comprehensive literature has given adequate understanding of the subject matter on welding of stainless steel which will be used in the future work on analysis of welding joint by different welding processes of stainless steel 316SS and 16 MnCr5 to carried out as the future work.

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