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Welding of Steel - Its Mechanism and Applications in Multiple Sectors

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Abstract

Among different metals steel can be easily welded and welded steel has required strength, good ductility and sufficient resistance to general corrosion media. Since steel welding is being used in all types of fabrication industries, the mechanism of steel welding has been explored for different types of steel along with its multiple applications.

Keywords: Steel welding, Mechanism, Carbon content, Alloying elements, Grain coarsening, Hardening, Pre-heating

1.0 INTRODUCTION

Steel welding joins two or more parts of steel together by means of heat, pressure or both to produce a joint. Very often filler material is used to produce a stronger weld than the base material. Welding existed long back in Iron Age and Bronze Age. It is essentially used in automotive, construction and the aviation industries. The growing community of artists make use of welding to create art work. It is being used to create many modern constructions in the world such as sky scrappers, cars, ships and airlines. Among different metals, steel is the easiest metal to weld and welded steels have high strength and enhanced ductility as well as the resistance to general corrosion media. Among all metals, steel is being widely used almost in all the sectors. Ever since the inception of steel its large varieties have been developed and the process of steel welding is being modified according to the type of steel as well as the needs and requirements in different sectors. In view of the significant contribution of steel in fabrication, the mechanism of steel welding has been discussed along with its application in multiple sectors.

1.1 Steel - the most popular metal to weld

Among different metals, only three metals steel, aluminium and copper are being used for welding in majority of sectors. Comparatively steel has maximum demand in most of the sectors due to its ductility, strength and versatility. Presently, a lot of varieties of steel are available to fulfil different kinds of needs and requirements in multiple sectors as the finished products meet the design dimensions without having any distortion and acquire the required strength. Steel welding is free from cracks or holes in the bead and beads have uniform waves, width and height.

1.2 Scope of welding

The first functional industrial robot developed to weld General Motor's Unimate hit the automotive scene in 1961 to perform spot welds. Welding made it to space in 1969. Further deep - sea welding went as low as 2,000 feet and this record was set by U.S. Navy in 2005 [1]. Now welding has set an invaluable skill in a number of industries from car production to international space station. These days welding processes find applications in aerospace, automotive, energy and construction. Presently welding is being widely used in different sectors such as aerospace, ship and boat building, railroads, manufacturing and construction and in Military too since it is an economical and affordable process.

2.0 STEEL - ITS DIFFERENT TYPES

Different types of steel are depicted in Figure 1 and each of these steels has been classified:

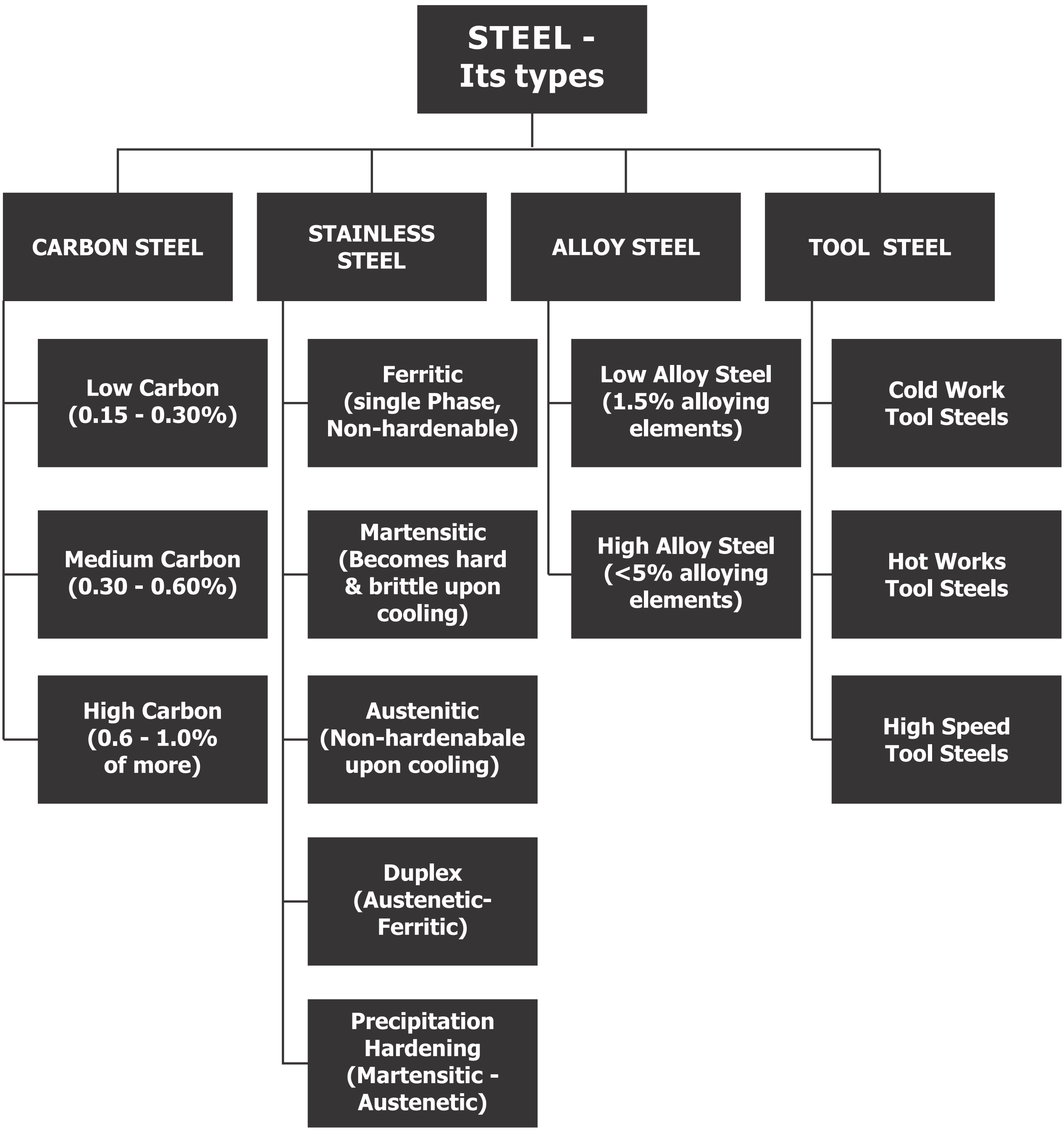

Fig. 1 : Steel-its different types

3.0 WELDING – ITS EARLIER PROFILE [2]

It is believed that ancient Egyptians developed the earliest form of welding around 4000 B.C.E. Earlier welding was started with copper and overtime moved to other metals namely iron, bronze, gold and silver. Around 310 B.C., Indian welders created the Iron Pillar of 25 feet height and six tons in weight which was erected at Delhi. It displayed the early craftsmanship of India. In 1375 C, E. the forge welding was at the forefront. Due to industrial revolution in 18th century innovative welding technology was developed. In 19th century Sir Humphry Davy discovered electric arc welding Fusion welding, bare metal electrode welding and carbon arc welding were invented and patented In 1881, Russian inventor Nikolay Benardos introduced carbon arc welding. Further thermit welding emerged in 1903 and C.J. Holslag invented alternate current welding in 1919 replacing electric arc welding in the United States. During the first and second world war scope of welding increased considerably. Since 19th century more efficient techniques have been developed for accurate, fast and effective welding. As such significant advancements in modern welding have taken place in Russia and England. Modern welding techniques offer better performance with safety and craftsmanship.

4.0 MECHANISM OF WELDING OF STEEL

Successful welding requires the understanding of materials and their properties. It involves the principles of physics, chemistry, mechanics and electronics. Their knowledge is extremely essential to comprehend the mechanism of welding of steel. In arc welding electric current is used to strike an arc between the base material and the consumable electrode rod made of filler material covered with a flux to protect the weld area from oxidation and contamination by producing carbon dioxide gas during the welding process. Electric arc is produced generating a very intense and concentrated heat when electric current is passed through an air gap from one electric conductor to another. As a result, consumable electrode melts and combines with the parent material to form a molten weld pool. Whereas gas welding is carried out by a flame produced by burning approximately equal volume of oxygen and acetylene with the flame temperature of approximately 3100° C high enough to melt the steel and other metals Other gases used in gas welding process are carbon dioxide, argon, helium etc. as shielding gases and acetylene, propane, butane etc. as fuel gases. Oxygen is used with fuel gases and also in small amounts in some shielding gas mixtures.

The mechanism of welding of steel depends upon

- (i) Carbon content in steel
- (ii) Alloying elements and their contents in steel
- (iii) Grain coarsening at high temperature
- (iv) Type of filler and its composition
- (v) Hardening effect at the welded joint
- (vi) High hardenability and quick cooling of welds
- (vii) Preheating, interpass temperature, cooling rate and post weld treatment

As the composition of steel changes from its one type to another, the mechanism of welding also changes in each type of steel accordingly.

4.1 Mechanism of welding of different types of steel

4.1.1 Welding of carbon steels

The carbon content in the steel plays significant role in its welding. The weldability of steel decreases with the increase in carbon content which increases its hardness. As a result, steel may become more prone to cracking.

(a) Low carbon steel

Low carbon steel can be readily welded in room temperature environment. The filler materials are designed to out form the base materials, with higher tensile and yield strengths.

(b) Medium carbon steel

Medium carbon steel with Mn from 0.60 to 1.65 % is susceptible to hardening during melting.

It is difficult to weld medium carbon steel due to hardening effect at the welded joint. It therefore requires preheat and post heat treatment in order to avoid cracking. This steel is preheated from 150°C to 250°C and preheating becomes necessary with the increase in carbon content. Both preheating and post–heat treatment are required to avoid weld cracking. Preheat also depends on the section thickness of the part to be welded. Any thickness below ¾ inch (19 mm) needs no preheat. It is welded using low hydrogen fillers.

(a) High carbon steel

High carbon steel with 0.60 to 1.00 % or more carbon is very difficult to weld because it readily forms the hard and brittle martensite phase as it cools down from welding temperature and it is prone to cracking. In order to avoid this, high carbon steel requires very thorough preheating and post heating. Internal stresses increase the risk of cracking and distortion. Proper preheating is required to slow the cooling rate of the finished weld and reduce the hardness in the heat affected zone (HAZ) creating less brittle and more ductile weld. Slow cooling rate of the weld and the base material results in softer weld metal as well as heat affected zone microstructures with greater resistance to fabrication hydrogen cracking.

4.1.2 Welding of stainless steel

Alloying elements present in different categories of stainless steel influence their weldability. All categories of stainless steel are not welded equally, some of them are more weldable while others are less [3].

(a) Ferritic stainless steel

Ferritic stainless steel is single phase and non-hardenable. It undergoes rapid grain growth at high temperatures leading to brittle heat affected zones. Due to the formation of brittle structure in heat affected zones weldability of steel becomes poor. Ferritic stainless steel is usually welded in thin sheets or sections having less than 6 mm thickness. In the case of thicker sections, a low heat input can minimize the size of the grain coarsened zone and minimize the sensitivity to cracking [4]. During the welding of ferritic stainless steel such filler metals are chosen which match or exceed the chromium level of the base alloy. Arc welding processes are used to weld ferritic stainless steel with limited heat input so as to minimize the grain growth.

(b) Martensitic stainless steel

Martensitic stainless steel is of two types namely low carbon (between 0.05 to 0.35 %) high strength and high carbon (between 0.60 and 1.5 %) high hardness. When joint cools to room temperature, the weld gets completely transformed to untempered martensite. Martensitic stainless steel can be successfully welded by taking precautions to avoid cracking in heat affected zone (HAZ) especially in thick section components and highly restrained joints. High hardness in heat affected zone makes this steel very prone to hydrogen cracking. The risk of cracking increases with the carbon content. It should be combated by using hydrogen conolled fillers. In the case of thicker sections and higher carbon materials, pre-and post- weld treatments are essential to reduce the risk of cracking [4]. For the welding of martensitic stainless steel, one must select such filler metals which match the chromium and carbon content of the martensitic metal.

c) Austenitic stainless steel

Austenitic stainless steel with austenite crystalline structure and face centered cubic lattice structure has high ductility, high formability and high toughness. Such a steel can be readily welded and does not require pre-or post weld heat treatment. For the welding of austenitic stainless steel such fillers should be used which have the matching composition to the base material. Austenitic steels with about 18% Cr and 10 % Ni are commonly used for welded fabrications.

Duplex (austenitic+ ferritic) stainless steel

Duplex stainless steel is the mixture of ferrite (bcc) and Austenite (fcc). It is welded with relatively high heat input and low interpass temperatures. During the welding of duplex stainless steel temperatures are chosen carefully since too much heat can compromise the structural integrity of the steel and render it useless. Duplex stainless steel relies on 50% austenite and 50% ferrite microstructure in the base metal. For the welding of duplex stainless steel one must select fillers quite carefully as the filler metal cools much more quickly in comparison to the base metal. Welding procedure should be so designed so as to produce same structure in the weld metal as well as in the heat affected zones. Such a structure is controlled by choosing appropriate weld thermal cycle, filler metal and protection atmosphere. The structure of duplex stainless steel is entirely ferrite near the fusion temperature.

(e) Precipitation hardening stainless steel

Precipitation hardening stainless steel is the combination of martensitic and austenitic stainless steel. Though its weldability is not at par with austenitic stainless steel, yet it is very good. It is welded without preheating treatment. However, it is heated in order to preserve its structural integrity after the weld has been completed. It is readily welded through standard fusion and resistance methods. One must take special care for its heat treatment so as to achieve optimum mechanical properties in the weld as in the parent material. The matching filler is selected and heat treatment after welding helps the weld to achieve close similarities to the parent material.

4.1.3 Welding of alloy steels

Compared to carbon steels and stainless steels, the weldability of alloy steel is poor since it is prone to cracking when welded. In view of this fact care is taken to preheat, interpass temperature, cooling rate and post weld treatment.

(a) Low alloy steels

Low alloy steels provide better mechanical properties with precise chemical composition. In order to avoid defects low alloy steels are welded with adequate precautions.

(b) High alloy steels

Compared to low alloy steels, high alloy steels have poor weldability and are prone to cracking. In view of this fact during the welding of high alloy steels special care is to be taken regarding their preheating, interpass temperature, cooling rate and post-weld treatment.

4.1.4 Welding of tool steels

Tool steels contain 2.5 % carbon apart from several alloying elements namely manganese, chromium, molybdenum, tungsten, vanadium and nickel. Three categories [5] of tool steel are cold work tool steel, hot work tool steel and high speed tool steel. The main characteristics of tool steels are hardenability, good toughness, wear resistance and heat resistance. These steels cannot be welded at room temperature, During the welding of tool steels considerable risk exists for their cracking. Therefore it is extremely essential to preheat their moulds or dies before making any attempt for their welding. Tool steels can be welded by common welding processes, The best process for their welding is gas tungsten arc welding (GTAW) based on its amperage and control over feeding and gas metal arc welding is a better choice for fast filling and joining large pieces [6].

4.2 Salient features of the mechanism of welding of different types of steel

The salient features of the mechanism of welding of different types of (i) carbon steel are shown in **Figure 2(a)** (ii) stainless steel in **Figure 2(b)** and (iii) alloy steel along with tool steel in **Figure 2(c)**.

Low carbon steel	• Easily welded at room temperature • Require filler with higher tensile and yield strengths
Medium carbon steel	• Difficult to weld because of hardening effect of heat at welded joint • Preheating from 150°C to 250°C in general • Essentail preheating and postheat treatment with increase in carbon content
High carbon steel	• Difficult to weld due to formation of hard and brittle martensite phase after cooling down • Through preheating and postheating to avoid the formation of hard and brittle martensite phase

Fig. 2(a): Salient features of the welding mechanism of carbon steel

Ferritic stainless steel	• Poor weldability due to rapid grain growth / excessive coarsening at high temperature leading to poor toughness in heat affected zone (HAZ). • Not hardenable by heat treatment and some grades may crack in the heat-affected weld zone. • Easily welded in thin sheets or sections with less than 6 mm thickness. • Requires filler with matching chromium of base alloy
Martensitic stainless steel	• Vulnerable to cool cracking leading to weld crack. • Transformation of weld to untempered martensite after cooling to room temperature. • Pre-and post- weld treatment needed to reduce the risk of cracking. • Requires filler with matching chromium and carbon content of martensitic steel.
Austenitic stainless steel	• Successful welding using any arc welding process. • Non-hardenable on cooling and no need for pre- or post- weld heat treatment. • Requires fillers to match the composition of the base material.
Duplex stainless steel	• Welded with high input and low interpass temperature. • Too much heat reduces structural integrity of steel. • Careful selection of filler metal as it cools quickly than the base metal.
Precipitation - Hardening stainless steel	• No need of preheating treatment. • Preserves structural integrity by heating the weld. • Heat treatment required after welding to achieve optimum mechanical properties. • Requires matching filler to have similarities with parent material.

Fig. 2(b): Salient features of the welding mechanism of stainless steel

Low alloy steel	• Care to avoid welding defects • Adequate precautions to provide better mechanical properties
High alloy steel	• Poor weldability and prone to carking • Special care for preheating, interpass temperature, cooling rate and postweld treatment
Tool steel	• High hardenability and weld cooling quickly • Considerable risk for cracking • Preheating of mould or die required before attempting to welding

Fig.2 (c) : Salient features of the welding mechanism of alloy steel and tool steel

5.0 APPLICATIONS OF WELDING OF STEEL IN MULTIPLE SECTORS

Depending upon the specific requirements different types of steel find applications in a number of sectors such as construction, automobile, petro-chemicals, railway, nuclear, aviation, transport, industrial machinery, energy, etc. However, carbon steels and stainless steels find major applications.

5.1 Carbon steels

5.1.1 Low carbon steel (Mild steel)

The welding of low carbon steel (mild steel) is used in the fabrication of pressure vessels and construction of bridges. Compared to riveted pressure vessels, low carbon steel welding has made considerable increase in the operating temperatures and pressures. Mild steel welding is also used in automobiles, furniture making, decorations, wire making, fencing, etc.

5.1.2 Medium carbon steel

The welding of medium carbon steel is often used for shafts, couplings, gears, axels, crank shafts, rails, etc.

5.1.3 High carbon steel

The welding of high carbon steel is mostly used in high hardness or wear parts, cutting tools, springs, and coils for the manufacturing industry as well as various washers and fasteners.

5.2 Stainless steels

5.2.1 Ferritic stainless steels

Ferritic stainless steels readily undergo cold working and deep drawing operations. The welding of ferritic stainless steel is used for industrial machinery, kitchen wares and automotive parts.

5.2.2 Martensitic steels

The welding of martensitic steel is very much used for automotive applications namely door beams, bumpers, rocker panels, cross car bars and beams to prevent intrusion into the passenger compartment.

5.2.3 Austenitic stainless steels

Austenitic stainless steel welding is used for domestic, industrial, transport, and architectural products because of its good corrosion resistance, formability and strength at extreme temperatures.

5.2.4 Duplex stainless steels

Duplex stainless steel welding is used in chemical process industries, petrochemicals, oil & gas, pharmaceuticals, geothermal, sea water desalination, liquefied natural gas., etc.

5.2.5 Precipitation hardening stainless steels

The welding of precipitation hardening stainless steels is used in aerospace and other high-technology industries. Its other applications are for making gears, valves and engine components.

5.3 Alloy steels

5.3.1 Low alloy steel

The welding of low alloy steel is used for construction equipment, ships, pressure vessels and piping as well as for oil drilling platforms. This welding is also widely used for the production of pipes, automotive and aerospace bodies, railway lines and offshore and onshore structural engineering plates.

5.3.2 High alloy steel

High alloy steel contributes high strength, hardness and toughness. Its welding is used mostly in infrastructure, automobiles, buildings, machines, ships, trains, appliances, etc. due to its high tensile strength.

5.4 Tool steels

The welding of tool steel is used to repair a broken die, fill in chipped surfaces, fix damaged sharp edges and recover worn features [7].

5.0 CONCLUSIONS

(i) The brief in depth study of the mechanism of welding of different types of steel reveals several mysteries related to their welding.

(ii) One must exercise more care and control with regard to heating and cooling of such steels during their welding.

(iii) It is extremely important to carefully choose the filler metals during the welding of these steels.

(iv) The filler metals should match with the material being welded.

(v) Compared to carbon steels and tool steels, stainless steels and alloy steels find significant applications in automotive, aviation, energy and construction sectors.

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