DEVELOPMENT OF AUSTENITIC STAINLESS STEEL TYPE 316LN – A REVIEW

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ABSTRACT

Iron based materials are widely used because of low cost and provides adequate mechanical properties such as ductility, toughness and high strength. Unfortunately mild steel and low alloy steel have poor resistance to corrosion and wear. There is a group of iron base alloys, iron-chromium-nickel alloys known as 'Stainless steel' which do not rust in most of the corrosive environments and do not scale at elevated temperature up to 1100°C. Since stainless steel has excellent corrosion resistance, small in tonnage and easily recyclable, its demand is increasing in many applications. Therefore, in this paper, development of different grades of stainless steel and its applications are discussed.

Key words: Stainless steel, grade, corrosion resistance, high temperature applications

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1. INTRODUCTION

Stainless steel is one of the most widely used materials today because of its corrosion resistance and strength. Its area of application is increasing continuously [1]. The term “stainless steels” relates to iron based- alloys of high corrosion resistance in environments where both iron and low alloyed steels would rust. It must contain more than 10.5wt% chromium. However, a minimum of 13wt% chromium is desirable for sufficient corrosion protection. The corrosion resistance increases with increasing rich surface film, usually referred as the passive film. The alloying elements improve the properties of the steel. The different grades of stainless steel have different

compositions. Hence, knowledge of the effect of alloying elements on structure and properties is essential.

Nickel promotes the repassivation and molybdenum stabilizes the passive film in chloride rich environments and hence on the corrosion resistance. The addition of molybdenum enhances resistance to pitting corrosion in salt water environments [2-4]. Carbon, titanium, aluminum, and copper are added for strength. The alloying elements particularly nickel, molybdenum and nitrogen are added to modify their structure and enhance properties such as formability, strength and cryogenic toughness [5]. Although stainless steels represent a low percentage of the total amount of steel produced, it has a technological and economic importance particularly in the chemical, petroleum, process and nuclear power industries.

2. STAINLESS STEEL

2.1. History of Stainless Steel

In 1889 AD, Riley of Glasgow discovered that the addition of nickel significantly enhances the tensile strength of the mild steel and in 1905, Portvin observed that steel containing more than 9wt% Cr was resistant to chemical attacks. The first attempts were made to use stainless steel for the practical applications during 1910-1915 [6]. The different grades of stainless steels alloys began around 1913 by researchers in Britain and Germany. The stainless steel containing 12.8 wt% chromium and 0.24wt% carbon was melted on 30th August 1913 in Sheffield, England by Harry Brearley and used for making barrels of heavy gun. It showed more resistance to abrasive wear [7]. Within a year of Brearley's discovery, Strauss and Meurer in Germany developed the first austenitic grades stainless steel with nickel additions.

Stainless Steel was found as a suitable material for protective tubing in thermocouple pyrometers. Simultaneously, Dannitzen in the United States modified Brearley's discovery with lower carbon contents and discovered the ferritic stainless steels [7]. Parallel with the work in England and Germany, Becket, USA, found that at least 20% (weight) of chromium was necessary to achieve resistance to oxidation or scaling for pusher type furnaces that were run at temperatures up to 1473 K. This was the starting point of the development of heat resistant steel. However, the Fe/Cr and Fe/Cr/Ni systems were understood around 1940 and stainless steels became standardized in 1950.

2.2. Passivation of Stainless Steel

Stainless steel has excellent corrosion resistance because of the presence of a "passive" chromium-rich oxide (Cr_2O_3) film that forms naturally on the surface. Even when it is scratched or cut, oxygen from the air immediately combines with chromium to reform the Cr_2O_3 layer [8]. Although the Cr_2O_3 layer is extremely thin (1-15 nanometers) and invisible, it adheres firmly and is chemically stable.

In the presence of water, the insoluble passive film is formed with a few millimeter thickness and consists of complex composition of iron oxides, chromium oxides, (inner barrier layer) and chromium hydroxides (outer layer) [9-10]. If the surface is damaged, the passive film immediately reforms under the influence of oxygen from water and/or air. An alloy element such as nickel and molybdenum produces another surface film. However, stainless steels cannot be considered to be "indestructible". The passive layer can be broken down under certain conditions. According to the end applications, the appropriate grade is to be selected.

2.3. Sensitization of Stainless steel

Sensitization is the precipitation of chromium rich carbides Cr_{23}C_6 or Cr_7C_3 along the grain boundaries during the detrimental heat treatments [11]. As a result, some chromium is lost and eventually it reduces the corrosion resistance property of the stainless steels [12]. This results in reduced ductility, toughness and aqueous corrosion resistance. During carbide precipitation, interstitial carbon diffuses rapidly into the grain boundaries. Unlike carbon, chromium diffuses slowly. Therefore, the chromium depleted zone is created. The deficiency in chromium at the grain boundary region is developed and reduces the corrosion resistance. This state is said to be in a sensitized state.

In high temperature applications, chromium depletion occurs at regions close to sensitization temperature range from 823 to 1123 K, and intergranular attack can arise. This type of corrosion is known as 'weld decay' [13]. There are many methods to control the effect of sensitization. One way is homogenization of grain boundaries by prolonged heat treatment. In another way, the addition of strong carbide formers such as titanium and niobium. The titanium and niobium prevents the formation of chromium rich carbides.

2.4. Development of Austenitic Stainless Steel

A variety of stainless steel grades were developed over the years. Each grade has different chemical composition and distinct advantages, since the structure of stainless steels at room temperature has decisive effect on properties. The base for the various stainless steels is the Fe-Cr system [14]. The main types of structure are austenitic, ferritic, martensite, precipitation hardened and Duplex (combination of austenitic, ferrite) [15]. Each structure contains different grades of stainless steels. The American Iron and Steel Institute (AISI) has designated different grades of stainless steels by three digit numbers. Some of the commonly used austenitic steels are identified as types 201, 301, 304, 316 [16]. Around 200 grades are available.

The austenitic stainless steel contains typically 12-25wt% Cr, 8-25% Ni and 0-6% molybdenum. The widely used austenitic stainless steels are AISI 304 and 304L grades and followed by AISI 316/316L. Together these grades make up over 80% of the total tonnage of stainless steels. Austenitic stainless steel is essentially an iron-chromium-nickel alloy containing chromium between 18 to 30 wt%, nickel 8-20% and carbon 0.01-0.03% [17]. It retains austenitic structure even at ambient temperature. Austenitic stainless steels are widely used in many sectors such as food, chemical, pharmaceuticals and building industries. The high levels of chromium contribute to the excellent corrosion resistance in austenitic stainless steel making it suitable for use in submarines and nuclear power plants. The addition of chromium helps to create a compact, continuous, insulating, coherent and regenerative protective oxide film on the surface [8].

2.5. Development of Low Carbon and Nitrogen Stainless Steel

The martensitic, ferritic, austenitic and ferritic-austenitic stainless steels were well established more than five decades ago. In those days, a common problem with these steels was the high carbon content which introduced the risk of intergranular corrosion due to precipitation of Cr_{23}C_6 along the grain boundaries. Hence, the production of the extra low carbon grades such as type 304L and type 316L have emerged. In these grades the carbon content is reduced to 0.03% (maximum) to improve the resistance to sensitization and avoids the corrosive attack at the grain

boundaries after welding (or) high temperature exposure. The lower carbon content minimizes the carbide precipitation in the affected zone near welds, which can lead to weld decay in certain environments. Except the 'L' grade stainless steels all other stainless steels are susceptible to sensitization.

In the late 1960's, the next development of stainless steels was made by Argon-Oxygen Decarburization (AOD) process. This technique was used to produce much cleaner steels with very low carbon level and well controlled nitrogen content. The reduction of carbon in stainless steels reduces the strength. Alternatively, the addition of nitrogen and lowering carbon content made it possible to develop nitrogen steels into readily acceptable materials. The addition of nitrogen as alloying element increases the strength and toughness without affecting corrosion resistance. It is called 'super' stainless steels. These super grades (304L, 316L) [27, 28] with very low interstitial levels and high chromium and molybdenum contents have superior corrosion resistance compared to standard grades.

By the introduction of nitrogen into bulk of the stainless steels, new classes of stainless steels known as nitrogen steels (304LN, 316LN) have evolved. If nitrogen is substituted for carbon in austenitic stainless steels, the mechanical properties can be improved without any adverse effects on their ductility and corrosion properties [18]. These highly alloyed super grade stainless steels are extremely low in carbon and offer combination of high strength with excellent corrosion resistance with better fabricability than ordinary grade. Nitrogen is more effective solid solution and stronger than carbon and also refines the grain size [19, 20]. Nitrogen is a strong austenitic stabilizer thereby reducing the amount of nickel required for stabilization. Nitrogen alloying also reduces the tendency to form ferrite and deformation induced α and ϵ martensite [21]. Since nitrogen alloying has greater solid solubility than carbon, it decreases the tendency for precipitation of carbides [22]. Tensile and yield strength of nitrogen alloyed stainless steels are reported to be higher than those of conventional series of stainless steels grades without sacrificing the toughness [23].

Nitrogen alloying has been found to be beneficial to fatigue resistance of austenitic stainless steels [24, 25]. It is also demonstrated that N_2 alloying stainless steel decreases the sliding wear and increases the cavitation erosion resistance (Hanninen et al 2001).

3. CONCLUSION

The development of different grades of stainless steel and its applications are discussed in detail. Although all grades of austenitic stainless steels provides corrosion resistance property, the austenitic stainless steels of grade AISI 316LN exhibits (i) strong corrosion resistance, (ii) strength at elevated temperatures, (iii) stability at cryogenic temperatures and (iv) ease of fabrication, including weldability. Hence, austenitic stainless steels of grade AISI 316LN are especially used in nuclear industries.

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