Schaeffler Diagrams

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Abstract

The increasing popularity of stainless steels in engineering applications has increased attention on the weldability of these alloys. The mechanical properties of the weldings are very sensitive to the specific final microstructure. That is why many different predictive diagrams and equations were proposed in the history, clarifying the compositional effects on the weld microstructure of stainless steels. These diagrams are also known as constitution diagrams. The Schaeffler diagram is a specific constitution diagram proposed by Schaeffler in different versions starting from 1947. The objective of this entry is to provide a detailed chronological history of the constitutive diagrams proposed in the technical literature, giving a panorama of the researches for predicting microstructures of stainless steel welds starting from the chemical composition of the steels.

INTRODUCTION

Stainless steels are an important class of engineering materials that have been used in a variety of applications. They can be considered as a group of highly alloyed steels based on the Fe–Cr, Fe–Cr–C and Fe–Cr–Ni systems. To be *stainless*, these steels shall contain a minimum of 10.5 wt.% chromium.[1] Unlike other materials, where classification is usually done considering the chemical composition, stainless steels are classified considering their predominant metallurgical phase. The three possible microstructures are martensite, ferrite, and austenite; duplex stainless steels contain approximately 50% austenite and 50% ferrite, taking advantage of the desirable properties of each phase. Precipitation hardened (PH) grades form strengthening precipitates and are susceptible to be hardened by proper aging heat treatments. PH stainless steels are further grouped by the phase in which the precipitates are formed, i.e., martensitic, semi-austenitic, or austenitic phases.[1,2]

Stainless steels are generally considered as weldable materials, but there are many rules that shall be considered to have defect-free weldings and with the expected microstructure for a good behavior in service.[3] More precisely, the residual δ-ferrite that can be found at room temperature once a stainless steel has been welded, i.e., after it has experienced the process of melting followed by solidification, will determine behavior during its service lifetime. It is well known that primary ferritic solidification avoids the hot cracking phenomenon in austenitic stainless steels, but the determination of the solidification mode requires a metallographic analysis, which is a destructive test. Therefore, in practical terms, a minimum δ-ferrite content of 3–4 FN (ferrite number) is considered an acceptable indicator to ensure the absence of hot cracking during solidification. However, for specific applications or service conditions, it is necessary to impose a maximum δ-ferrite content, e.g., for high-temperature conditions or thermal cycles (350–900°C) when δ-ferrite can suffer from spinodal decomposition or be transformed into (σ) sigma-phase, causing embrittlement and a decrease in corrosion resistance.[1,2] It is also necessary to establish a maximum δ-ferrite content in the case of stainless steels used under cryogenic conditions, as it influences the material's ductility and the low-temperature toughness.[1,2]

The relationship between the δ-ferrite content and the mechanical and corrosion-resisting properties in stainless steels has encouraged researchers to discover predictive tools and measurement methods since the early part of the twentieth century. Predictive methods are essential during the design stage of a project in order to have a good approach to the δ-ferrite level that will be achieved, when a weld deposit or pad is not available, or when different options of welding consumables are being considered.

That is why many different predictive diagrams and equations were proposed in the history, clarifying the compositional effects on the weld microstructure of these alloys. These diagrams are also known as constitution diagrams. The Schaeffler diagram is a specific constitution diagram proposed by Schaeffler in different versions starting from 1947.

The aim of this entry is to provide a detailed chronological history of the constitutive diagrams proposed in the technical literature, giving a complete panorama of the researches for predicting microstructures of stainless steel welds starting from the chemical composition of the

Encyclopedia of Iron, Steel, and Their Alloys DOI: 10.1081/E-EISA-120050782