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Chapter 1

Introductory Chapter: Why Austenitic Stainless Steels are Continuously Interesting for Science?

Zbigniew Brytan, Wojciech Borek and Tomasz Tański

Additional information is available at the end of the chapter

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1. About Austenitic Stainless Steels

The history of stainless steels begun in the twentieth century with first works of Monnartz (Germany) in 1908 that discovered passivity in Fe-Cr alloys when Cr content reach 12% and introduced the property of "stainlessness" for metallic alloys. Thanks for studies on Cr-Ni-Fe alloys made by Mauer and Strauss (Germany), the first patents were issued in 1912 for two nickel-containing stainless steels. In this way, the history of austenitic stainless steel began. Today the austenitic stainless steel of classic composition 18%Cr, 8%Ni (grade 304 L) is still the most widely used by far in the world. The first commercial melt of austenitic stainless steels was emerged in 1913 due to works of Hary Brearley (G.B.). In 2013, Stainless Steel celebrated its 100 years and was one of the significant materials' developments in the last century. The stainless steel is still one of the fastest growing materials. The unique characteristic of stainless steel arises from three main factors. The versatility is resulting from high corrosion resistance, excellent low- and high-temperature properties, high toughness, formability, and weldability. The long life of stainless steels has been proven in service in a wide range of environments, together with low maintenance costs compared to other highly alloyed metallic materials. The retained value of stainless steel results from the high intrinsic value (contains expansive alloying elements—nickel) and easy recycling. Stainless steel, especially of austenitic microstructure, plays a crucial role in achieving sustainable development, nowadays so important for further generations [1–3].

The growing consumption of austenitic stainless steels is driven by scientific developments in this field, regarding new grades of improved or optimized properties, studies on corrosion resistance in various environments or microstructural phase transformations ongoing during service or fabrication. The purpose of the book is to present most exciting field of scientific research related to austenitic stainless steels and creep-resistant austenitic alloys. Present chapters deal with different aspects of alloy design. First of all, are associated with

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the effect of work hardening on microstructure and mechanical properties. One of the most exciting field in austenitic stainless steel development concern studies on work hardening mechanism of Fe-Cr-Mn-Ni-based austenitic stainless steels. Understanding the influence of deformation-induced processes on the strain hardening behavior and tensile elongation is essential to the economical design of highly formable austenitic stainless steels. The occurrence of various deformation-induced processes such as deformation-induced ε/α′-martensite formation mechanisms in austenitic steels is governed by the stacking fault energy (SFE). The influence of alloying elements on the SFE of austenitic stainless steels can be deduced from their influence on the $M_d^{\gamma \rightarrow \alpha'}$ temperature. Therefore, relationships giving the compositional dependence of $Md^{\gamma \rightarrow \alpha'}$ temperature can be used as guidelines for the design of austenitic stainless steels with improved properties [4, 5].

Austenitic stainless steels during austenite to martensite transformation may develop the magnetic response, as martensite is ferromagnetic. Therefore, the martensitic transportation induced by plastic deformation in austenitic stainless steels can also be studied using selected cross effects. The application of the magnetomechanical effect (the Villari effect) and the thermomechanical effect (the Kelvin/Thomson effect) turned out to be particularly useful in this case because, they change significantly with martensite initiation and then accumulation in austenite. This approach gives the opportunity to develop non-destructive methods of investigating the martensite transformation and allows follow and visualizes transformations online during the fatigue process, without the necessity to use, for example, roentgenographic or microscopic methods. This method can also be introduced in both laboratory conditions and on real constructions made of metastable austenitic steels [6, 7].

The book chapters discuses also an essential field of studies concerning microstructural phase transformations ongoing during service at high- and low-temperature conditions. The stainless steels are susceptible to secondary precipitates under service. Precipitation of sigma phase represents one of the most potentially dangerous degradation mechanisms in austenitic stainless steels. Understanding the microstructural changes ongoing during long time exposure at elevated temperature lays in the basis of the creep resistance properties of stainless steels. The understanding relation between cold work plastic deformation, mechanical properties including creep and the structural changes with the particular attention to precipitated intermetallic phases during long-term high-temperature exposure is essentials to predict the lifetime of engineering applications. The changes of the structure and mechanical properties is extensively studied both for the base austenitic steels grades in annealed conditional, and after cold bending or welding, that can further accelerate precipitation of sigma phase, supplying more deeper view on observed degradation processes [8–10].

The high-temperature service conditions require creep-resistant alloys of the austenitic or ferritic microstructure. The creep-resistant alloys during service undergo progressive degradation of their microstructure, which results in the changes of functional properties. The main microstructural mechanisms of degradation include the processes of matrix softening, the processes of precipitation and matrix depletion of the interstitial and substitution elements. The precipitation processes ongoing during service plays a significant indicator of microstructure degradation processes. Therefore, such processes are essential in diagnostic of

components and equipment in service and make possible to forecast the time of safe operation. The characteristics of secondary phase precipitate occurring in creep-resistant steels, especially most frequently used austenitic creep-resistant grades is essential to the understanding of ongoing degradation processes [11, 12].

Apart from high-temperature applications of creep-resistant austenitic alloys, the austenitic stainless steels are frequently applied in low-temperature service conditions. High toughness at the low-temperature of austenitic stainless grades, in contrast to ferritic or duplex alloys, makes them particularly suitable cryogenic applications. The effect of intergranular precipitation on the low-temperature toughness of nitrogen alloyed austenitic stainless steels plays an essential role in cryogenic applications. The presence of intergranular nitride precipitates causes a severe decrease in toughness for stainless steels subjected to sort high-temperature cycle. Nitrogen alloyed stainless steels exhibit the presence of intergranular brittle fracture as a result of the grain boundary nitride precipitation. This behavior may be especially crucial during the welding, because of the short aging time for precipitation. The more profound understanding of precipitation processes involves thermodynamic stability and growth kinetics analysis of the precipitated phases, during a high-temperature cycle. For such a purpose, computational thermodynamics and the so-called CALPHAD method wave been frequently applied [13, 14].

The austenitic stainless steels are not free from corrosion problems. The book also deals with most frequently local corrosion phenomena encountered in these alloys. The local corrosion processes like intergranular corrosion (IGC) occurring in stainless steels remains in the interest of science. Therefore, alloy design strategies also focused on alloying of austenitic stainless steels by single or combined addition of nitrogen, molybdenum, and silicon. Based on such alloying principles, many austenitic stainless steels grades can be defined, dedicated to resisting local corrosion in chloride-containing media and nitric acid [15].

Studies on corrosion resistance also include modification of working conditions, thus the introduction of corrosion inhibitors to an acidic environment. The research on corrosion inhibitors is even going in the direction of organic compounds, for example, rosemary oil and aniline that can significantly reduce the corrosion rate of stainless steels in sulfuric acid [16, 17].

Austenitic stainless steels are well weldable, even though different problems have often been reported during the welding operation. These issues are also addressed in the book. Welding of stainless steel using friction welding becomes more interesting nowadays. The problems encountered in friction welding during joining of austenitic stainless steel are very limited when compared to fusion welding process. Therefore such technic can be useful for joining dissimilar metals, for example, joining of austenitic stainless steel and copper base alloys. Evaluation of friction welding parameter and understanding of ongoing metallurgical phenomenon plays a key role in finding the good bond strength between dissimilar metals [18].

Applications of austenitic stainless steels, apart from corrosion environment action, also involve in mechanical loads. The nature and intensity of such loads can be detrimental for each engineering equipment, thus must be determined and studied through basic microstructural mechanisms. The knowledge of their character is crucial in maintaining the required

mechanical properties of the elements and the entire system made of stainless steels. The fracture mechanisms, thus reasons of nucleation and propagation of cracks of different size (from micro- to macro-cracks) under low cycle fatigue conditions is essential to modern high-risk systems, like nuclear applications. For this reason, different grades of austenitic steels as prospective materials for structural parts subjected to extreme cyclic loading and severe environmental conditions have been studied. The nucleation of microcracks in the austenitic, fine-grained steels was observed in slip bands and the critical factor in the destruction of the material is assigned to precipitates and grain boundaries. The microcrack propagation process and its correlation with the steel microstructure are also quite disputable. Despite numerous experimental results on alteration of microcrack propagation direction, there is no convincing hypothesis explaining the real reasons for the process [19, 20].

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