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Review

Evolution of stress–strain models of stainless steel in structural engineering applications

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HIGHLIGHTS

- This study provides are detailed study of stainless steel models.
- Early stainless steel models provided the basis for new models.
- All models are developed by fitting analytical curves to test data.
- Ramberg–Osgood is the best model up to 0.2% proof stress.
- New models are derived to cover stresses at larger strains.

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ABSTRACT

Stainless steel is a family of steel alloys with a minimum of approximately 10.5% mass of chromium. Unlike carbon steel, it has high corrosion and heat resistant properties. Stainless steel does not easily corrode because it forms an invisible thin passive film of about 5×10^{-6} mm of chromium oxide (Cr_2O_3), which is impervious to water and air. If this film is damaged by scratching, it repairs itself as chromium in the steel reacts rapidly with oxygen and moisture in the environment to re-form the oxide layer. Since the early 20th century a lot of research work has been performed to understand the stress–strain response and mechanical properties of materials which exhibit non-linear behaviour over the complete shape of the stress–strain curve. Significant progress was achieved when the Ramberg–Osgood model was developed, however, there is consensus among researchers that this model is only accurate up to the 0.2% proof stress. As designs become more complicated and refined, it is clear that the behaviour of non-linear materials cannot be fully described by the Ramberg–Osgood model. Advanced numerical analysis and design requires knowledge of the stress–strain relationship of the alloys over a full range of the stress–strain curves. This paper provides a detailed review of the evolution of the stress–strain models of stainless steel, in literature.

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1. Introduction

The family of stainless steel is generally classified, according to their crystal structure, into five groups, namely; Austenitic stainless steels (17–18% chromium and 8–11% nickel), Ferritic Stainless steels (10.5–18% chromium), Martensitic stainless steels (similar to ferritic steels), Precipitation hardening stainless steels (similar to 18% chromium and 8% nickel austenitic steels) and Duplex stainless steels (21–26% chromium, 4–8% nickel and 0.1–4.5% molybdenum). In the past, there has been a perception that the different groups of stainless steel behaves in the same way as carbon steel. Several research have actually shown that stainless steel exhibits different mechanical properties from carbon steel [1–11]. Unlike carbon steel, which exhibits an elastic behaviour up to the yield stress and a plateau before strain hardening, stainless steel exhibits non-linear stress–strain behaviour at much lower stress levels (approximately at 36–60% of the yield strength) than carbon steels (assumed to be at least 70% of the yield point) [11], with no well-defined yield stress (Fig. 1). What complicates the behaviour of stainless steel is that the degree of *roundedness of* the stress–strain varies from one group of stainless steel to another, and sometimes it varies within the same group, depending on the composition of the alloy. Austenitics are the most widely used stainless steels in the structural steel industry, and show the largest non-linearity. Since stainless does not have a defined yield point, its yield strength or proof strength is defined for a particular off-set strain, usually 0.2% strain (Fig. 1).

Stainless steel exhibit anisotropy or different material properties in the longitudinal and transverse direction, possess greater ductility and experience significant enhancement of corner strength properties than carbon steel during the cold working process. This means that they can absorb considerable impact without fracturing, and results in higher residual stresses than carbon steels. The work required to fracture the material is proportional to the area under the stress–strain curve. As a result of the vast difference in material properties between carbon and stainless steel and between the different groups of stainless steel, it is necessary to determine appropriate models for stainless steel alloys. Numerous models have been proposed to describe the non-linear behaviour of stainless steel, with austenitic steel showing the largest non-linearity and strain hardening properties than other stainless steels.

2. Early strain hardening models

The shapes of the stress–strain curves of non-linear materials has generated considerable interest since 1938, particularly for elements in compression, which may buckle at stresses beyond the elastic limit of the material. This is not surprising since the two commonly recorded properties, yield strength and elastic modulus, are insufficient to describe the complete shape of the stress–strain curve, unless the material follows Hooke's law up to the yield point, and thereafter yield indefinitely under constant stress. Early

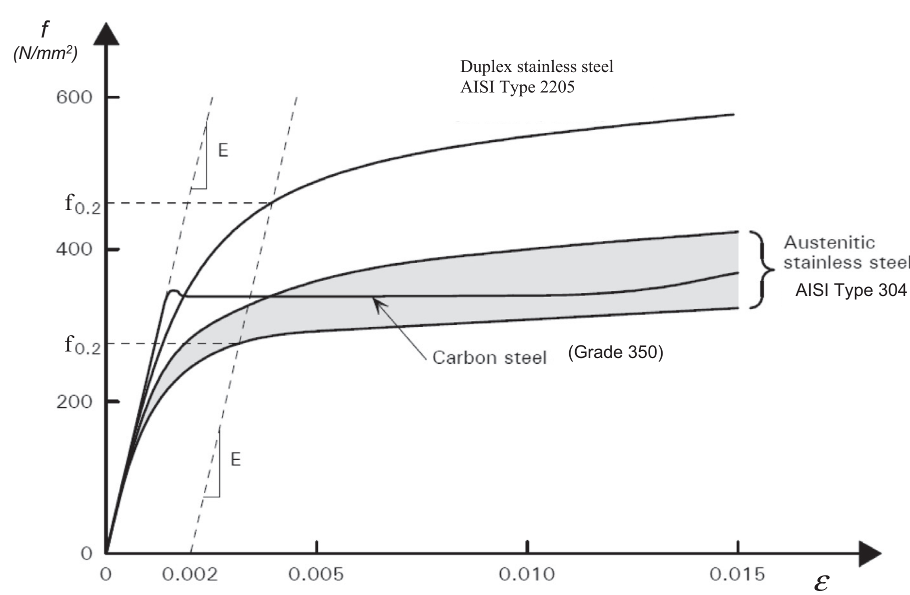

Fig. 1. Typical stress–strain curves for carbon and stainless steel.