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Mini Review

A Mini Review on the Degradation of Young's Modulus in Steels

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Abstract

In this mini review the degradation of Young's modulus is discussed, along with what influences the degradation. In the automotive industry, parts need to be formed from metals such as steels, aluminum, etc., at an incredibly fast pace but face considerable challenges. One of these challenges is the springback which occurs after forming. The correction takes time away from forming parts to critical geometries and requires more work to reform to the specified parameters. The springback can be worse if the materials show degradation of Young's modulus. Based on several research papers of various steels, there are several parameters that affect Young's modulus that are explained in a coherent approach. Microstructure, ferrite/austenite volume fraction, rolling direction, and prestrain are the main factors that affect the values for Young's modulus degradation in steels..

Abbreviations: TRIP: Transformation Induced Plasticity; HSLA: High Strength Low Alloy; DP: Dual-Phase; BH: Bake-Hardened

Introduction

The automotive industry is currently under considerable pressure to adapt to environmental laws or standards to reduce emissions and increase the efficiency of their vehicles. Engineers are finding ways to reduce the amount of steel used in the vehicle to reduce the weight, while still maintaining the engineering and safety requirements. The main problem in the automotive industry is the effect of elastic recovery or the springback. Elastic recovery or springback is when the metal slightly reverts to its original shape after being formed. This becomes a problem when a part must be formed to a specific geometry that is essential to the safety and engineering standards requirements. Springback is a common phenomenon within metals such as steels, aluminum, etc. The springback depends on the initial Young's modulus, and the amount of prestrain applied to the material in plastic deformation. Normally in the automotive industry mild steel is used for the bodies of vehicles, due to its high formability. The problem with this steel is that it exhibits low strength, which makes it limited in other applications. Most researchers conduct experiments on AHSS steels such as DP and TRIP for their high strength and high ductility compared to conventional steels. However, AHSS steels are limited in the automotive industry due to the challenges in forming, tool life, sheet metal coupling, and springback behavior. The springback is the main problem with AHSS steels, which compromises the mass-production of automotive structural components, *Nikhare et al.* [1-2]. Springback is affected by the microstructure of retained austenite and retained martensite, which affects the young's modulus of steels *Nikhare et al.* [1]. Understanding the effects of young's modulus can alter the springback, and other mechanical properties in steels.

Findings

Young's modulus as stated in the introduction, is the measure of stiffness of the material when subjected to a stress. This is shown from subsequent loading/unloading tests in plastic region which characterizes the Young's modulus behavior. As the AHSS steel becomes strained, the Young's modulus degrades, until it reaches the saturation point, where it remains constant throughout further straining [1-10]. The orientation of the steel has a significant role in the degradation of the elastic modulus. The three common rolling directions of the steel are 0°, 45°, and 90° to the rolling direction Figure 1. These orientations show different non-linear paths of elastic modulus degradation, which can be fitted by an average elastic modulus (E_{av}) by using equation 1, *Nikhare et al.* [1].

$$E_{av} = E_0 - (E_0 - E_{SAT})\left[1 - \exp\left(\xi\varepsilon^p\right)\right]$$

Where E_0 is the initial young's modulus; ε^p is the prestrain value; E_{SAT} is the saturated young's modulus; and ξ is the material parameters indicating the modulus decay rate Figure 2. Various steels show change in Young's modulus upon loading/unloading as shown in Table 1. TRIP (Transformation induced plasticity), HSLA (High Strength Low Alloy), DP (dual-phase), and BH (bake-hardened). The difference in hat treatments of the steel, changes the behavior of the mechanical properties [1, 3-6].

Comparing the two metals DP780 and DP1000, it is observed that the DP780 steel has a smaller elastic recovery than the DP1000, *Julsri et al.* [5]. The elastic modulus decreases in a nonlinear fashion, when the steel is subjected to strain, *Halilovič et al.* [7]. Pre-straining the steel increases the rate of degradation of young's modulus when the steel is subjected to strain [4,8]. Prestraining the steel perpendicular to the rolling direction, causes the young's modulus to degrade at a greater rate [7,8]. It is also important to note that the degradation is also greater when the steel is not oriented in the rolling direction, meaning it has the most significant amount of degradation when the rolling direction is 90°, *Panin et al.* [9]. It has been reported by *Cobo et al.* [10], that the reduction in young's modulus decreases with respect to decreasing the ferrite volume fraction. This is due to the dislocation movement within body dentered cubic ferrite structures is easier than in body centered tetragonal martensite structures. Consequently, the local micro-plastic strain is in smaller quantities when the steel has a greater ferrite volume fraction, but the higher martensite volume in the microstructure will generate a higher plastic micro-strain *Nikhare et al.* [1].

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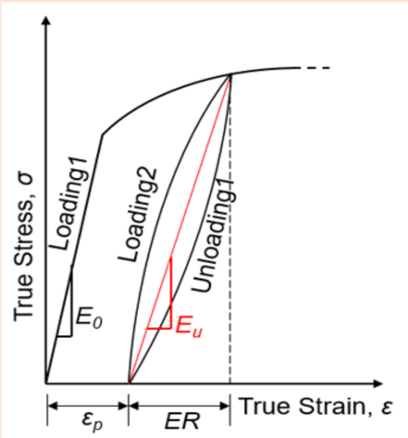

Figure 1: Material true stress-strain curve with intermittent unloading and loading (εp-plastic strain, ER-elastic recovery).

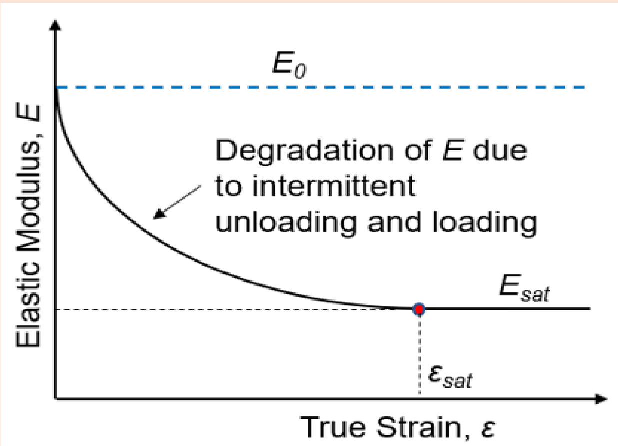

Figure 2: Degradation of elastic modulus due to intermittent unloading and loading of a material (εsat-Elastic modulus saturation strain).

Table 1 : The elastic properties of various types of steels

Material [Source]	Initial Modulus (E0) GPa	Saturated Modulus (ESAT) GPa	Saturation Strain (εSAT)
Mild270 [3]	225	171.2	0.12
BH340 [3]	198.2	162.1	0.1
HSLA-65 [4]	210	120	unclear
HSLA-490 [1]	207.1	176.4	0.208
DP490 [3]	204.9	159	unclear
DP590 [3]	196.5	159.2	0.05
DP-780 [5]	199.85	168.6	0.064
DP-980 [1]	207.9	185	0.114
DP-1000 [5]	208.91	128.4	unclear
TRIP700 [6]	196	155	0.12
TRIP-780 [1]	208	161.8	0.285

Conclusion

In this mini review, several effects are covered that change the young's modulus degradation in steels. A table has been constructed to show the comparison of the Young's modulus degradation in various types of steels. In short, Young's modulus degrades more significantly with respect to pre-strain. The rolling direction orientation affects the young's modulus degradation. It also decreases as ferrite volume fraction decreases or when the austenite volume fraction increases. It is recommended to characterize the AHSS material and model the material behavior accordingly to predict the springback in the desired part.

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