GalvInfoNote

2.8.1

Strain Ageing in Galvanized Low Carbon Steel Sheet

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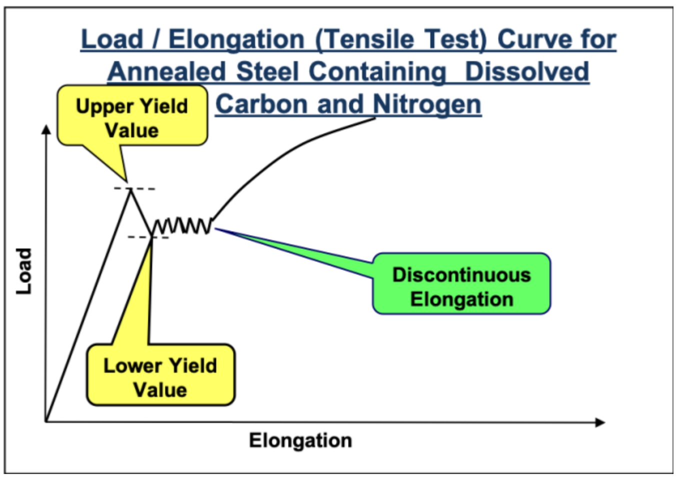
Introduction

“Metals have shear strengths several hundred times less than the theoretical shear strength needed to produce elastic deformation of a crystal”[1]. The reason for this behavior is the presence of *dislocations,* i.e., imperfections in the metallic crystal lattice. The strength required to move a dislocation is much less than lattice binding strength. This GalvInfoNote explains how dislocations are related to the phenomenon of strain ageing.

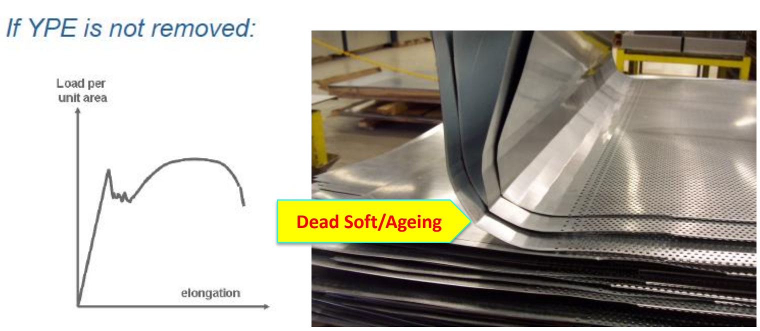
Discontinuous Yielding

When strained, some metal alloys, such as low carbon steel (including galvanized sheet), begin yielding at an Upper Yield value related to the generation of new dislocations from the stress, as shown below.



One way this behaviour manifests itself is as fluting during bending of a sheet as shown here.

Discontinuous Elongation/Yielding

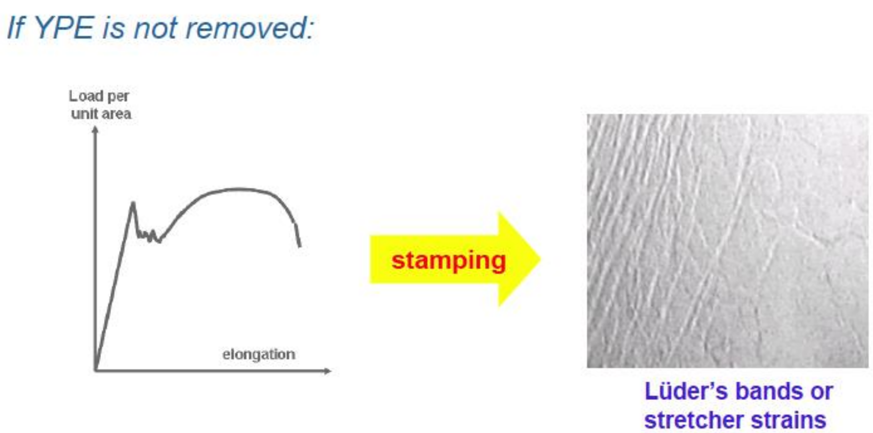


Once dislocations are created they traverse, extending the metal at a lesser strength value called the Lower Yield, i.e., the metal softens at the point where it first starts to deform – and for some time deformation is localized with no additional load. This causes "discontinuous elongation/yielding" - a ratcheting behavior in the stress/strain diagram due to dislocations alternately generating at higher stress and traversing at lower stress. From the Upper Yield point to the end of discontinuous deformation is called Yield Point Elongation (YPE). The stress value associated with this onset of dislocation movement is typically considered to be the Yield Strength (YS) for low carbon steel sheet. Beyond the YPE portion of the stress-strain curve, further increasing the load causes additional plastic elongation as more dislocations are generated and traverse, which results in permanent plastic deformation. Eventually, dislocation blockages and tangles "work harden" the metal until it fails at its Ultimate Tensile Strength (UTS).

Strain Ageing

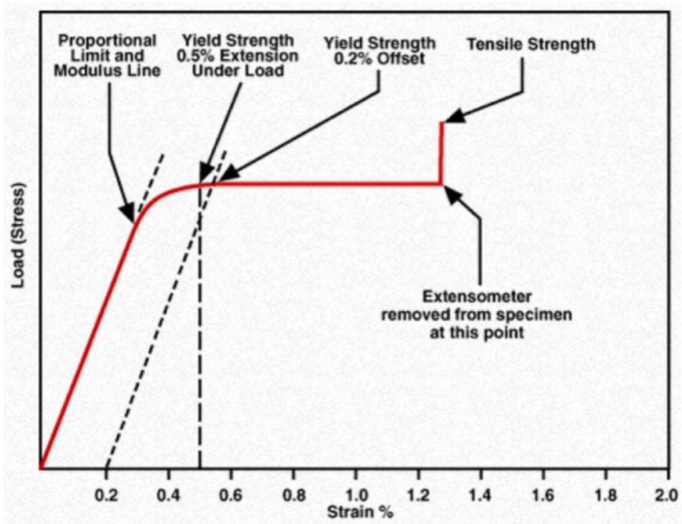
"Strain aging is a behavior, usually associated with the yield point phenomenon, in which the strength of a metal is increased and the ductility is decreased on heating at a relatively low temperature after cold working."[2] The upper yield point returns with time and/or temperature, along with the fluting and stretcher strain it causes. In low carbon steel, strain ageing is the result of carbon and nitrogen atoms, which exist in a supersaturated solid solution in iron, diffusing to dislocation sites with time and temperature. Steel with carbon and nitrogen remaining in solid solution will strain age at room temperature. Nitrogen, though, plays a more important role in the strain aging of iron than carbon because it has a higher solubility and diffusion coefficient, producing less complete precipitation during slow cooling. The reappearance of the yield point is due to the diffusion of carbon and nitrogen atoms to the dislocations during the aging period to form new atmospheres of interstitials anchoring the dislocations. Support for this mechanism is found in the fact that the activation energy for the return of the yield point on aging is in good agreement with the activation energy for the diffusion of carbon in alpha iron[3].

From a practical standpoint it is important to eliminate strain aging in deep drawing steel because the reappearance of the yield point can lead to difficulties with Lüders bands (stretcher straining) due to the localized heterogeneous deformation. This is shown below:



The occurrence of serrations in the stress-strain curve is a direct result of discontinuous, or repeated yielding. It is also called the Portevin-Le Châtelier effect[4]. This phenomenon is due to successive yielding and aging while the specimen is being tested. This results from the fact that, in the range of temperature in which it occurs, the time required for the diffusion of solute atoms to dislocations is much less than the time required for an ordinary tension test. Stretcher strains can also form during the time it takes to draw flat sheet into a shape during press forming.

The most common method of eliminating discontinuous elongation/yielding is to remove the Upper Yield Point by using cold deformation to create dislocations and/or dislocation sources within the steel. A minimum of about 0.5 % elongation is required. Both temper rolling and roll intermesh tension leveling can achieve this objective adequately – and the selection of which process is applied normally depends upon surface requirements for the product. Freedom from stretcher strain for a period of 6 months can be achieved by skin-passing or by tension leveling with higher extensions of 1.25 to 2.0%, although working the sheet this much must be considered carefully, lest the resulting higher mechanical properties interfere with formability. The resulting stress-strain curve is shown below. The most common method of specifying the yield strength of such a curve is the 0.2% Offset method. See GalvInfoNote 2.8 for a more in-depth discussion of stress-strain plots.



Another method to control strain aging is to lower the amount of carbon and nitrogen in solution by adding elements which will take part of these interstitial atoms out of solution in the form of stable carbides or nitrides. Aluminum, titanium, niobium, and boron can be added for this purpose. While a certain amount of control over strain aging can be achieved, there are almost no commercial low-carbon steels which are completely non-strain aging. Also, a disadvantage of adding carbide and nitride formers to low carbon steel is that the more precipitates that form, the progressively harder the steel becomes due to these small particles preventing dislocation movement. To obtain formable deep drawing and extra deep drawing steels that are completely free of aging, they must be made as *ultra-low carbon (0.002 %C or less)*. Even then, the remaining carbon and nitrogen needs to be stabilized with just enough titanium and/or niobium so as to be taken completely out of solution from the iron matrix. Such steels, also known as stabilized interstitial-free (IF) steel, will never strain age, nor flute, nor show Lüders lines.

In the case of low carbon steels, and because of the above factors, it is also essential that the period between final processing at the mill and fabrication be kept to a minimum. Rotation of material by using the oldest first is important. Stocking of such steels for extended periods of time should be avoided; for optimum performance, the period should not exceed 6 months.

Note that the onset of strain aging in low carbon coated sheet produced on continuous galvanizing lines can sometimes be rapid and severe when the sheet is leveled or skin passed in-line at temperatures above 38˚C. Cold working at these temperatures can cause a rise in Rockwell B hardness by as much as 10 points in a period as short as 2 weeks after production. It is most likely the result of the carbon and nitrogen being "activated" to more easily return to and be pinned by dislocations. This can be more of an issue in locations where ambient mill temperatures are above this. The solution is to chill the sheet to less than 38˚C before the leveler and skin pass units – which sometimes is not a trivial task.

For material that has an upper yield point, effective leveling immediately prior to processing at the user's plant can achieve reasonable freedom from stretcher strain and fluting.

Summary

Because low carbon steel sheet, whether metallic-coated or not, is widely used in manufacturing myriad products, the effects of strain ageing can be sometimes be a frustrating issue for users to deal with. This technical note explains why strain ageing happens and offers processing and chemistry countermeasures to minimize its effects.

[1] Dieter, Jr, George E., Mechanical Metallurgy, McGraw-Hill, New York, 1961, p. 96
[2] Ibid, p. 135
[3] Ibid, p. 135
[4] Ibid, p. 136