

HSS

# ARTICLE

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## HEAT TREATING HSS

by Jeffrey A. Packer  
Bahen/Tanenbaum Professor of Civil  
Engineering, University of Toronto,  
Ontario, Canada

HSS in North America are produced as cold-formed members by one of the following methods:

- (i) Cold-forming into a round initially, closing the section using electric resistance welding (ERW), and then potentially cold-shaping into a square or rectangular section. Production can be to ASTM A500 (ASTM, 2013), A847 (ASTM, 2014a), A1085 (ASTM, 2015a), CSA G40 (CSA, 2013) or even the ASTM A53 (ASTM, 2012) pipe specification.
- (ii) Cold-forming directly to a square or rectangular shape, and closing the section using ERW. Production can be to ASTM A500, A847 or A1085 specifications.
- (iii) Cold-forming directly to a square or rectangular shape, and closing the section using submerged arc welding (SAW). Production in this case should conform to ASTM A1065 (ASTM, 2015b).

## HEAT TREATING

In practice, post-production heat treatment is an available finishing option with two of the above manufacturing standards: ASTM A1085 and CSA G40. Some HSS production plants have the ability to perform heat treatment on site, but usually it involves transportation of the HSS to a third-party heat-treating facility. Ordering will generally need to be done directly with a producer, and heat treatment will entail extra cost. Heat treatment is available with A1085 by specifying Supplement S1, and with CSA G40 by specifying Class H. Both of these standards describe identical heat treatment, at a temperature of 850 °F (450 °C) or higher, followed by cooling in air. Canadian manufacturers of product to CSA G40.20-13/G40.21-13 Grade 350WT Class H Category 2 Toughness should be able to demonstrate, through mill test reports, that all of the requirements of ASTM A1085 with Supplement S1 are met, for dual certification.

What are the advantages of such heat treatment?

1. The primary effect of heat treatment at 850 °F is the provision of partial stress relief throughout the cross section. Cold-formed HSS is subject to a very high amount of cold working during the forming process, particularly in the corners of thick-walled square and rectangular HSS. Typical residual stresses in continuous-formed and direct-formed ERW HSS can be seen in Sun and Packer (2014a), with longitudinal residual stresses reaching up to 70 to 75% of yield, around the cross section. In the corners, the measured yield stress may be elevated by over 40% relative to the flats, and the corresponding elongation at failure (ductility) reduced by up to 50% relative to the flats. The longitudinal compressive residual stresses lower the proportional limit in the compressive stress-strain curve, if one tested a stub column of the HSS in compression; i.e. first yielding of the cross section occurs at a lower applied compression load. This causes the axial compressive strength of an intermediate-length column (which is the practical range where the column is not so short that it squashes at  $AF_y$ , nor so long and slender that it buckles elastically at the Euler buckling load of  $\pi^2 EI/L^2$  to be reduced. Thus, heat treatment may lower the measured tensile yield stress, relative to its cold-formed parent, at the test location (in the flats), but will serve to raise the compressive strength of intermediate-length columns. Considering that HSS to ASTM A1085 is guaranteed to have a minimum yield strength (for design) of 50 ksi, with or without Supplement S1, one would expect columns with Supplement S1 heat treatment (and the same yield strength at the test location) to have a higher axial load capacity, which they will. Unfortunately, in the United States designers cannot take advantage of this difference in column capacity because AISC 360 Chapter E (AISC, 2016) prescribes the same “column curve” for all compression members failing by flexural buckling (AISC 360 Commentary E1). In Canada, on the other hand, the steel design standard CSA S16-14 (CSA, 2014) uses two column curves and assigns heat-treated HSS to the upper curve and cold-formed HSS to the lower curve.
2. Heat treatment will increase the ductility of the HSS, particularly in the corners. There are applications where low corner ductility is a concern, and heat treatment will ameliorate this situation. The standard for hot-dip galvanizing, ASTM A143 (ASTM, 2014c), cautions that cold-worked steel may be susceptible to embrittlement, which can then be accelerated by galvanizing. Hot-dip galvanizing involves immersion of the steel into a bath of molten zinc (with traces of other elements) at a temperature of approximately 850 °F, but at a rapid rate. A143 recommends a cold-bend radius of at least  $3t$ , where  $t$  is the material thickness, to ensure a satisfactory result. This is actually the *upper* limit for the outside corner radius in HSS to A500 and A1085, and in fact this radius averages  $2t$  (which is even used for the calculation of square and rectangular HSS section properties). For these tight bend radii, A143 Section 6.3 recommends proper thermal treatment of the steel before galvanizing. For deformations induced by roll forming, A143 recommends either normalizing the steel or stress relieving at a *maximum* of 1100 °F (595 °C), for one hour per inch of thickness, to avoid excessive grain growth. This recommended pre-galvanizing treatment temperature is met by A1085 Supplement S1 and CSA G40 350W Class H. One provider of the latter HSS grade publishes a heat treatment of 30 minutes in their furnace at a temperature of 890 °F (480 °C).

Heat treatment at a temperature in the range of 850 to 900 °F does not affect the metallurgical properties to the extent of influencing the toughness. It has been shown, by laboratory testing, that such heat treatment does not provide any improvement in the Charpy V-notch (CVN) toughness of North American cold-formed HSS (Kosteski et al., 2005; Sun and Packer, 2014b).

## HOT FORMING

Hot forming, or hot finishing, involves making various shapes of finished hollow section, commencing with a round shape produced by cold-forming with ERW or by hot-forming seamless tubes. However, a unique feature of this complete process involves heating (or re-heating) the closed tube to achieve full normalizing, to above the upper critical transformation temperature of 1600 to 1700 °F (870 to 930 °C), and finishing to final shape in this condition. This produces a fine-grain metallurgy and good toughness, with very low residual stresses and uniform properties around the cross section. Structural tubing is not manufactured in North America by this process, but is available in Europe to the standard EN 10210 (CEN, 2006a, 2006b). Certain EN 10210 grades comply with ASTM A501 (ASTM, 2014b) which is the U.S. standard to which such HSS are imported to North America. These hollow sections might be specified for special situations where the metallurgical properties are desired, elliptical shapes are required, or very thick-walled round HSS are needed.

## HOT BENDING

Hot bending entails local heating and then bending the member to a desired radius using a chosen bending method. Hot bending is generally selected when the bend radius is too small for cold bending. For curving HSS members the use of induction bending is typical, with an induction heating coil placed around a short length of the member. Complete stress relief of the HSS will occur during this extreme heating. This process should produce beneficial metallurgical changes in the heated and bent regions, similar to hot forming (described above).

In Japan, a post-production process is used to locally modify the walls of cold-formed HSS by applying local induction heating to a region of an HSS where a connection will subsequently be made. A dramatic increase in CVN toughness has been shown to occur in the “hot formed” regions of the HSS (i.e., the absorbed energy vs. temperature curves shift to the left).

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