

## Effect of Martensite Start and Finish Temperature on Structural Steel Welds

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### Introduction

Martensite start and finish temperatures are very important in structural steel welding because they control the residual stresses in a weld. Tensile residual stresses amplify the effect of applied tensile stress. On the other hand, compressive residual stresses are algebraically added to the applied tensile stresses to result in a lower net stress level experienced felt by a welded component, thus inhibiting crack initiation and increasing the fatigue life of the welded specimen.

The compressive residual stress pattern and magnitude depend on the expansion that accompanies the austenite-to-martensite transformation and the thermal shrinkage due to cooling. High martensite start temperature and low martensite finish temperature will both minimize the effect of transformation-induced compressive stress generation. Obtaining a full martensitic structure within an optimal range of temperatures will depend mainly on the filler metal composition.

### Technical Approach:

This investigation was carried out to determine the martensite start and finish temperatures of welds using ferrite-martensite and ferrite-austenite composition filler metals. The compositions of the wires are shown in Table 1. The base metal was A36 carbon steel. Automatic gas metal arc welding (GMAW) equipment with a constant power source was employed, using direct current electrode positive (DCEP) to prepare three layers (six passes) of weld beads for each of the wires. Appropriate welding conditions were selected to ensure defect-free welds. Specimens from the welds were machined for microstructural analysis and dilatometric testing to determine the martensite start and finish temperatures.

Table 1. Compositions of Wires.

Wires	C	Mn	Cr	Ni	P	Mo	Si	S	Ti
A1	0.03	1	11	0.35	0.016	0.006	0.31	0.0010	0.0019
A6	0.03	1	16	0.35	0.016	0.006	0.31	0.0010	0.0019
B5	0.03	1	16	2.35	0.016	0.006	0.31	0.0010	0.0019
C5	0.03	0.3	3.5	15	0.023	0.5	0.01	0.0010	0.0019

The dilatometric measurements were done on a Gleeble thermomechanical simulator using 6 mm diameter, 80 mm length samples. The samples were heated to and held at 1050°C for three minutes, follow by quenching in a helium jet at a cooling rate of 100°C/s. Eight samples were tested, two from each electrode. Kallings reagent was used to reveal the microstructures of the four sets of welds.

**Results & Discussion:**

Result of Ms temperature for the different designed wires evaluated is listed in Table 2. Table 2 also contains the Ms temperature estimated by the Self, J. - Olson, D. Equation (1986) and Ghosh, G. and Olson, G. (1996,2002) proposed model estimated the martensite start temperatures.

Table 2. Martensite start temperatures.

Wires	Experimental Ms Start Temperature (°C)	Self-Olson Equation Ms Start Temperature (°C)	Ghosh and Olson Ms Start Temperature (°C ± 40)
A1	416	309	340
A6	360	239	334
B5	301	301	330
C5	279	114	208

The Self-Olson Equation as shown below is:

$$M_s = 521 - 350 C - 13.6 Cr - 16.6 Ni - 25.1Mn - 30.1Si - 40.4Mo - 40 Al - 107 Cr.Ni + 219(Cr+0.73Mo)C$$

The Ghosh and Olson proposed a model to describe the composition dependency of the critical driving force including the effect of both interstitial and substitutional. In this model transformation occurs when embryos of martensite, which are defects bounded by interfacial dislocations, can grow against the lattice friction experienced by these dislocations. The fault energy of the martensite embryos is mainly dependent on the driving force  $\Delta G^{\lambda \rightarrow \alpha} = G_\alpha - G_\lambda$ , and must exceed the interfacial frictional work for nucleation to occur. In this model, to predict the Ms temperature for a steel of known composition the critical driving force were estimated from the composition using the empirical formula:

$$-\Delta G_{M_s} = K_1 + \sqrt{\sum_i (K_\mu^i X_i^{0.5})^2} + \sqrt{\sum_j (K_\mu^j X_j^{0.5})^2} + \sqrt{\sum_k (K_\mu^k X_k^{0.5})^2} + K_\mu^{C_0} X_{C_0}^{0.5}$$

where  $i = C, N$ ;  $j = Cr, Mn, Mo, Nb, Si, Ti, V$ ;  $k = Al, Cu, Ni, W$  and  $K_\mu$  is the athermal strengths solutes for the the f.c.c./b.c.c. martensitic interface.

Using the a thermodynamic database, a computer program could search for the temperature  $T = M_s$  providing  $\Delta G^{\lambda \rightarrow \alpha} = \Delta G_c$ , where  $\Delta G_c$  is the critical driving force for nucleation.

As can be seen in Table 2 Ghosh and Olson approach allows a much wider range of applicability than linear regression (Self- Olson equation). The thermodynamic method provides satisfying results, as long as it is used within compatible with fundamental assumptions upon which was built. However, this model also explicitly limits itself to solid

solutions, implying that the influence of precipitates or grain size cannot be accounted for. Because of this, it would be the slightly differences comparing with experimental values.

On the other hand, Self-Olson equation was derivate from different range of elements than the filler metal composition, especially the percentage of carbon is higher (0.08 %) than these, being C the element which has the strongest influence on martensite temperature start in Self-Olson equation. Therefore, this equation Only seem to provide more accurate results, when the material composition is in the range of that from which it was derivate.

The residual stresses were measured in all welds by biaxial strain gage. The value of residual stress was  $-200$  MPa at two millimeters from the weld using the C5 wire.

**Conclusions:**

Results indicate:

- (i) that the microstructure in all the welds were martensitic,
- (ii) the value of martensite transformation temperatures obtained were closer than that predicted by Ghosh-Olson approach.
- (iii) the results of dilatometric testing indicates the designed wires can induced compressive residual stresses around the weld toe.
- (iv) the residual stresses determined indicate compressive behavior.

