Deformation and Hardening Characteristics of Structural Steel Under Post-Fire and Fire Conditions

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Abstract

The microstructural and mechanical properties of low carbon steel as a function of temperature and post thermal exposure are characterized. The amounts and morphology of carbides present were monitored as a function of thermal exposure parameters. An Internal State Variable (ISV) model has been employed to simulate the flow behavior of the steel for multiple temperatures, ranging from 20-700°C and loading rate conditions. Low cycle fatigue tests are carried out to determine the material parameters required for implementation in constitutive equations.

Relevance

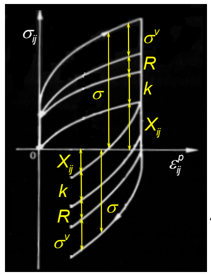
This work provides a fundamental understanding of the deformation response associated with fire loadings. It also gives insight on the effects of microstructural components related to the deformation response of post-fire loading conditions. This knowledge represents the foundation of predictive modeling of new designs, materials and protocols for mitigation methods aiming at infrastructure protection.

Accomplishments Through Current Year

1) Effects of temperature and time on Vol% pearlite and grain size of low carbon steel have been examined. **2)** An ISV material model combining kinematic and isotropic hardening has been employed. **3)** An experimental program was carried out to determine material parameters for model implementation. **4)** Numerical modeling was carried out for 1-D simulation to check validity of model and its ability to predict material behavior for variable loading conditions.

Technical Approach

1. Internal State Variable Model



$$\sigma_v = |\sigma - X| - R - k$$

$$X = X_1 + X_2$$

$$\dot{X}_i = C_i(a_i\dot{\varepsilon}_p - X_i|\dot{\varepsilon}_p|) - \beta_i|X_i|^{r_i-1}X_i$$

$$\dot{R} = b(Q-R)|\dot{\varepsilon}_p|$$

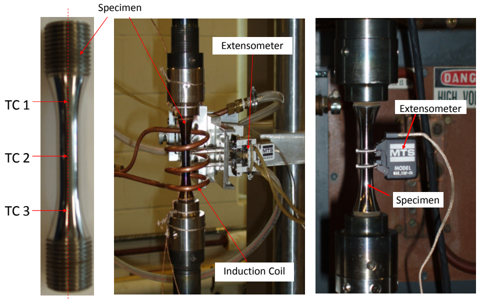
$$Q = Q_{max}\left(1 - e^{-\mu q}\right)$$

$$q = \max(|\varepsilon_p|, q)$$

$$\dot{\varepsilon}_p = \left\langle\frac{\sigma_v}{K}\right\rangle^n \exp\left(\alpha\left\langle\frac{\sigma_v}{K}\right\rangle^{n+1}\right) sign(\sigma - X)$$

$$\dot{\sigma} = E(\dot{\varepsilon}_t - \dot{\varepsilon}_p)$$

2. High & Room Temperature Test Setup



3. Experimental Program & Parameter Determination

Strain controlled tests carried at 5 temperatures to determine Kinematic Hardening, Isotropic Hardening, and Viscous Stress Material Constants. Tests required at each temperature are:

1. Monotonic – constant strain rate

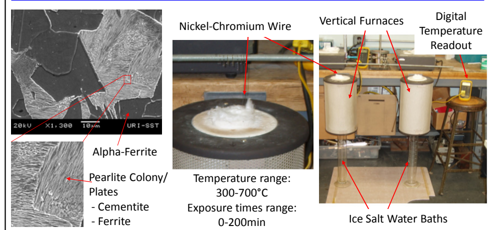
2. Stress Relaxation – constant strain rate with hold at constant strain values

3. Cyclic – constant strain rate with fully reversed loading at different strain ranges

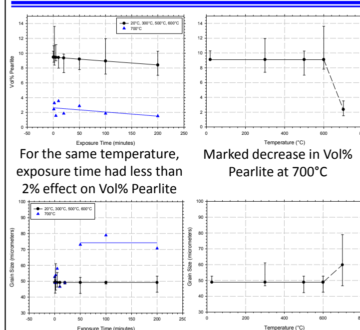
4. Strain Rate Sensitivity – varying strain rates

4. Microstructural Characterization

5. Heat Treatment Test Setup



6. Quantitative Analysis

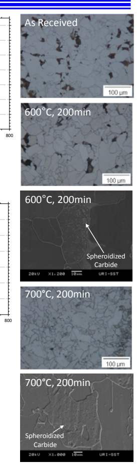


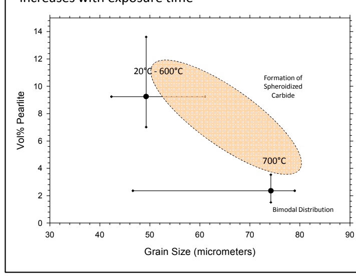
For the same temperature, exposure time had less than 2% effect on Vol% Pearlite

Marked decrease in Vol% Pearlite at 700°C

For T 20°C- 600°C, exposure time has no effect on grain size. At 700°C, "average" GS increases with exposure time

Increase in variations of grain size at 700°C (bimodal distribution)





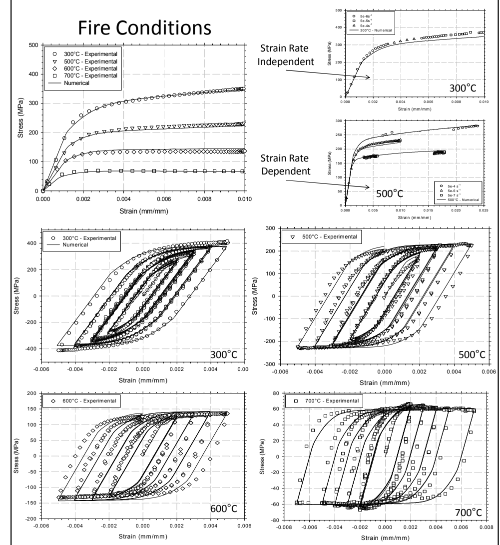
Critical Post Fire Conditions

- As Received
- 600°C, 200min, Quenched in Ice Salt Water Bath
- 700°C, 200min, Quenched in Ice Salt Water Bath

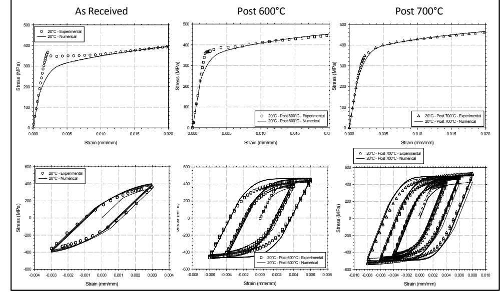
7. Simulation Results & Validation

The ISV model is capable of modeling:
Monotonic and cyclic loading for all temperature conditions:
A) 20°C and 300°C - strain rate independent behavior
B) 500°C, 600°C, and 700°C - strain rate dependent behavior

Fire Conditions



Post-Fire Conditions



Future Work

This ISV model is being extended to 2-D and 3-D simulations suitable for implementation of steel-structures subjected to fire and loading conditions. It will also be extended for simulation of deformation response of structural steel under combined blast/fire loadings

Journal Publications

K. Maciejewski, Y. Sun, O. Gregory and H. Ghonem, Time-Dependent Deformation of Low Carbon Steel at Elevated Temperatures, Int. J. Steel and Iron Research, March 2011

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