A Study of the Effect of Heat Treatments on EN9 Steel – Grain Structure and Mechanical Properties

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Introduction

Heat treating is a procedure which involves using heat to alter a material's properties. There are many heat treatment procedure which alter these properties in different ways. The properties which are targeted in heat treating a metal are the hardness, toughness, strength and ductility. The heat treatment of metals manipulates the grain structure which consequently modifies the mechanical properties.

Normalising

Normalising is completed by heating the steel to the austenitizing temperature, allowing the whole specimen to transform to austenite, then cooling in air to ambient temperature.

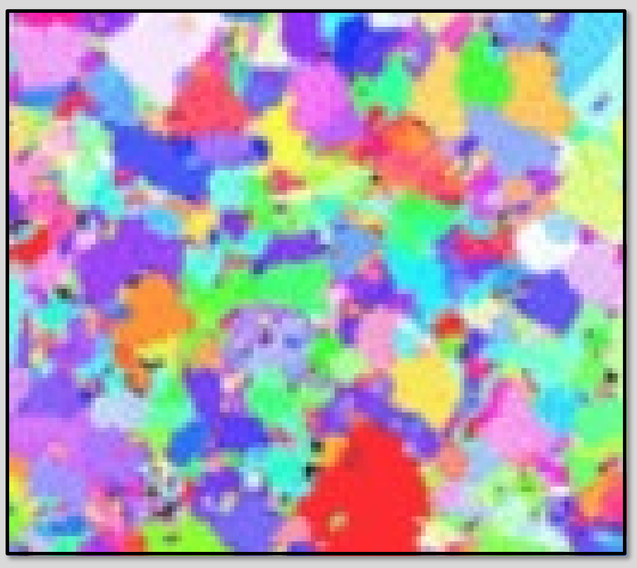

Figure 1: EBSD image of the microstructure of normalised steel.

Quenching

Quenching is also austenitising the steel, but then subjecting it to rapid cooling to ambient temperature.

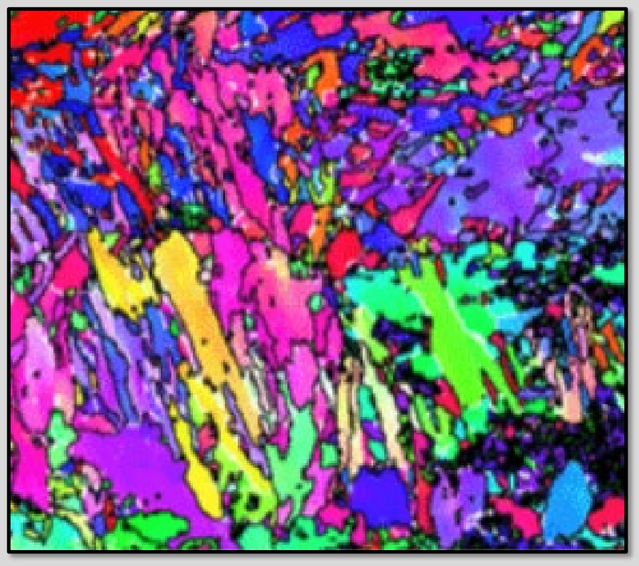

Figure 2: EBSD image of the microstructure of steel tempered at 180°C. This is very similar to that of quenched steel.

Tempering

Tempering is the process of reheating quenched steel to below the eutectoid temperature, holding it at that temperature for a set period of time, then allowing the steel to cool in air to ambient temperature.

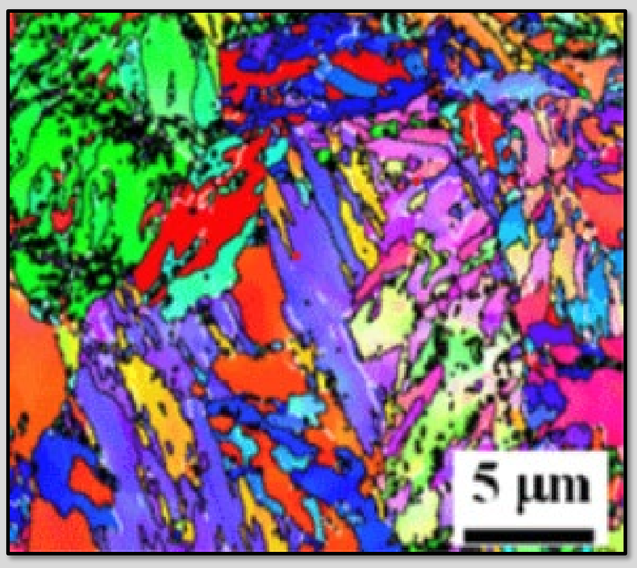

Figure 3: EBSD image of the microstructure of steel tempered at 500°C.

Experimental Procedure

EN9 steel specimens, presented in Fig. 4, 5 and 6, were heat treated to create five different test parameters: normalised, quenched and tempered at 250°C, 450°C and 650°C. Charpy impact, tensile and hardness tests were then completed to obtain mechanical data. EBSD microscopy was to then be completed but COVID-19 prevented this.

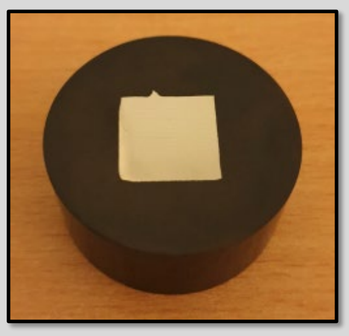

Figure 4: EBSD microscopy specimen.

Figure 5: Tensile test specimen.

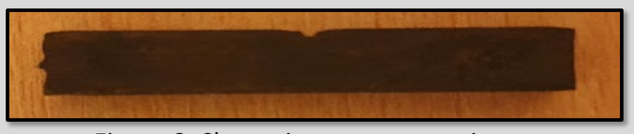

Figure 6, Charpy impact test specimen.

Results

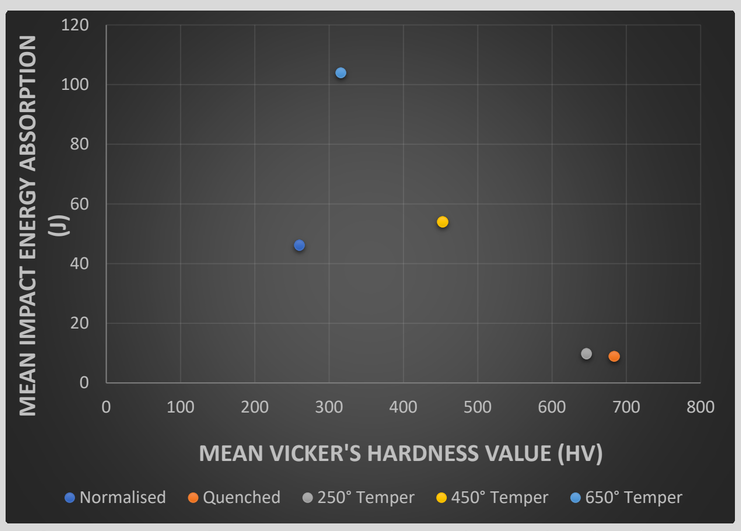

Figure 7: Mean impact energy absorption against hardness.

From Fig. 7 it can be seen that through tempering, the toughness increases by 47.1J for every 250°C increase, and also the toughness exceeded that of normalised steel.

Figure 8: Mean yield stress against hardness.

Figure 8 shows that hardness positively correlates to yield strength. This then also correlates higher yield strength to smaller grains, as the EBSD images show smaller grains for harder specimens. This data therefore agrees with the Hall-Petch relationship.

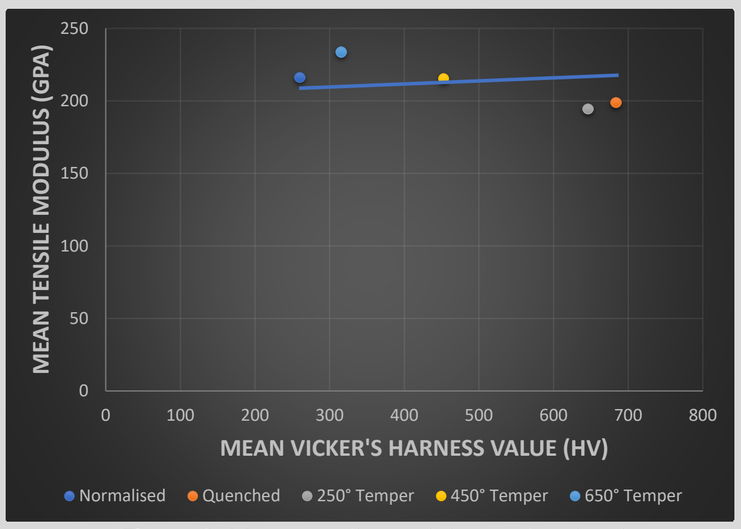

Figure 9: Mean tensile modulus against hardness.

From Fig. 9 it can be observed that through tensile testing there is no significant change in tensile modulus when the steels are subjected to different heat treatments.

Conclusions

From the experimental procedure carried out the following conclusions can be made:

- Temperature of tempering and toughness positively correlate, even surpassing the toughness of normalised steel.
- There is no significant effect of heat treatment on tensile modulus.
- EN9 steel adheres to the Hall-Petch relationship, where smaller grains lead to higher yield strength.
- EN9 steel is not susceptible to temper embrittlement, where the toughness decreases when tempering temperatures exceed 400°C.