Overheating of AISI4140

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Details:

A number of companies supplying AISI4140 components for hardening and tempering can experience mechanical test failures caused by the process routes prior to heat treatment.

Investigation:

Components supplied to heat treaters sometimes achieve low mechanical test values especially in regard to impact tests post heat treatment. The composition on the mill cert shows the material should be capable of achieving mechanical results far better than obtained before and after heat treatment.

An example of this problem is an investigation that took place on a particular batch of component. The steel was purchased from a well-known mill and of high quality. It had been forged prior to heat treatment. On heat treating the first batch through a standard heat treatment route, it showed poor mechanical results.

This prompted an investigation, at first to obtain the chemical analysis and compare it to the original mill cert. On receiving the results (Refer to Table A) it confirmed that the composition is close to that stated on the mill certification.

	%C	%Mn	%SI	%P	%Cr	%Ni	%Cu	%Mo	%Al
Mill Cert	0.41	0.81	0.3	0.014	1.03	0.14	0.03	0.24	0.027
Components composition	0.42	0.8	0.3	0.012	1	0.14	0.028	0.24	0.026

Table A

The next stage was to investigate the potential problems hot working and heat treatment may have on the material. The main problems are as follows:

1. Metal flow related problems: for example: end grain and poor surface performance; inhomogeneous grain size; shear bands and locally weakened structures; adiabatic shear bands; cold shuts; laps and folds; flow through defects.

   The direction on which the components are forged can have an effect on impact properties (in general transverse impacts are always lower then longitudinal impacts after a forging or rolling operations). In general the test house does not know the direction of the grains (i.e. which way it has been forged). Therefore rely heavily on the specifications to tell them where to test.

2. Fracture related problems: for example internal bursts, chevron cracks, cracks on free surfaces and cracks on die contacted surface – this would be evident during the microstructure examination.

3. Pre heating for forging and excessive heat treatment: Excessive grain growth, burning of grain boundaries, brittle structure, decarburization, quench cracking. When certain low alloy steels like AISI4140 are heated to +1200°C for long periods of time during the forging stage, it can have an additional effect on the grain boundaries due to manganese and Sulphur melting in the austenite state and the during cooling re-precipitating, it vastly reduces the properties of a material. This Phenomenon is known as "overheating" and it may not always be reversed during a standard heat treatment operation.

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Microstructure

As the structure is not homogeneous it is evident that there are areas of course and areas of fine grains. This is what is known as "badly heat treated steel". This material was overheated during the hot working operation and then the components were placed in stillage's and left to cool. The problem of stacked and therefore crowded components in the stillage, leads to various uneven cooling rates around the component, therefore depending on the components position within the stillage depended on what cooling it received. These components weighed 26Kg so the microstructure did vary at different positions (see phots below).

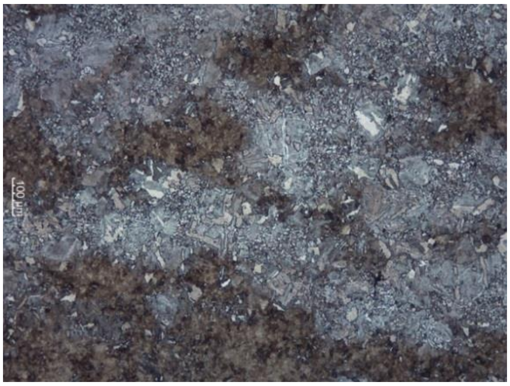

Photo A

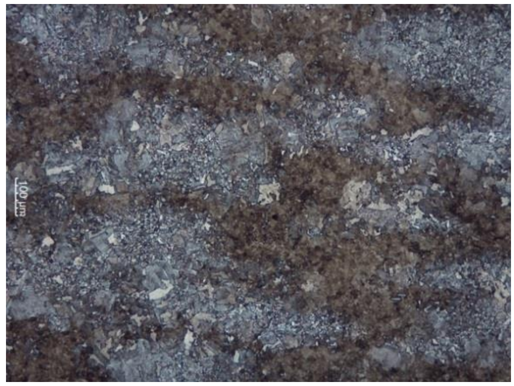

Photo B

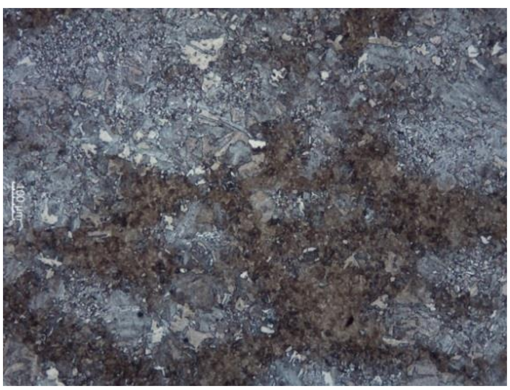

Photo C

Photo A, B, C – Martensite (dark), ferrite/pearlite aggregate (light), bainite (large grains) x100

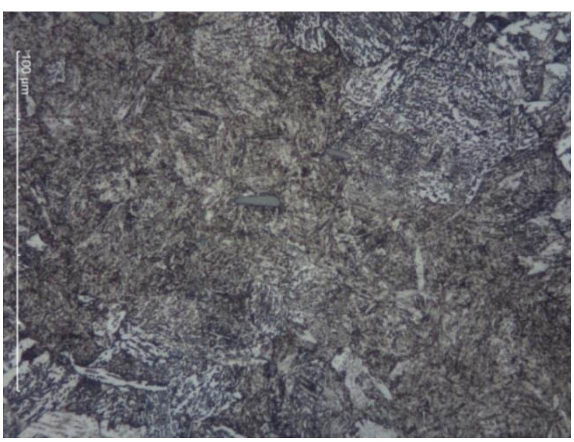

Photo D – Martensite with MnS inclusion x400

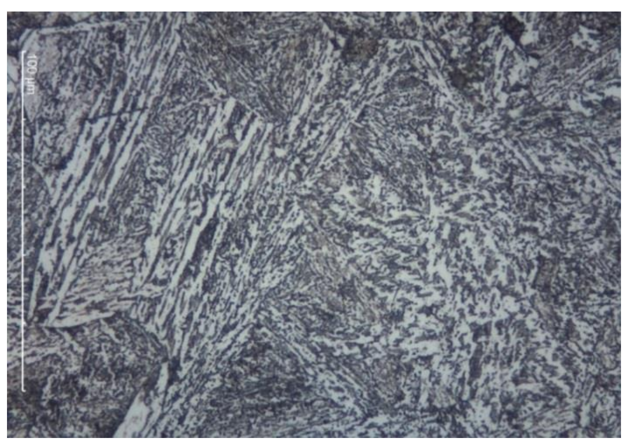

Photo E – Ferrite/pearlite aggregate x400: pearlite is normally formed on delayed cooling from austenite

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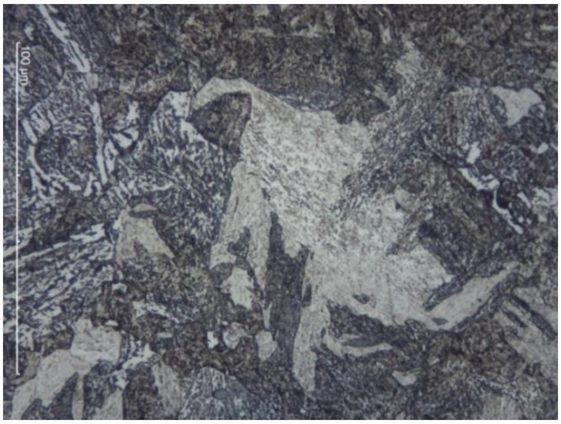

Photo F – Martensite (dark), ferrite/pearlite aggregate (light), bainite (large grain) x400

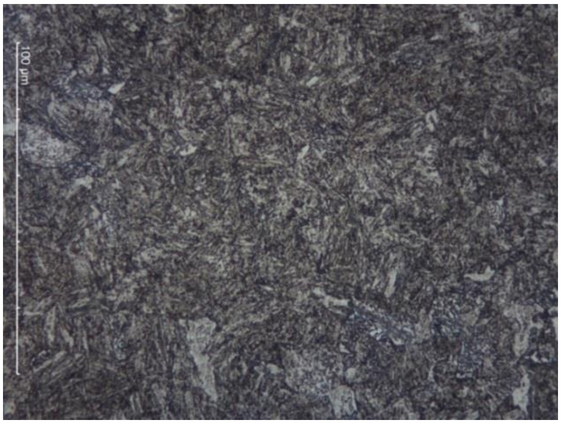

Photo G - martensite x400

Why and How to Detect Overheating

When a low alloy steel like AISI4140 is heated at too high a temperature prior to forging, localised melting occurs at the austenite grain boundaries, which causes segregation of phosphorus, sulphur, and carbon. On cooling, manganese sulphides probably form within the phosphorus-rich austenite grain boundary, which then transforms to ferrite. This weakens the grain boundaries hence the poor mechanical results that occurs after heat treatment.

Detection of overheating can be difficult, the two etchants that are recommended are, nitric-sulfuric acid and ammonium nitrate solution. After etching you need to pay attention to the grain boundaries to see if you can see a series of spots on the grain boundaries. These spots do indicate that manganese sulphides are present, but depending how overheated the material was, will depend if you can see them on a conventional microscope. In general it is very difficult to detect them. (Reference: T.J. Baker and R. Johnson, J. Iron Steel Inst). The best method of detection is by use of an SEM machine, but this can be very costly.

Factors Affecting Overheating

The main factor that determines the severity of overheating is all down to the composition; sulphur greatly influences overheating. If a steel has less than 0.002 wt% sulphur, overheating is vastly reduced due to the low amount of sulphides formed. As the sulphur content increases so does the severity of the overheating and also the temperature that this phenomenon commences. Phosphorus is the next element to be aware off, the richer the content the more susceptible the material will be. Other factors that have an affect are: temperature, cooling rate, and method of manufacture.

To avoid overheating, selection of the correct heating temperature is paramount, also the time it is at high temperature. During heating it is important to ensure the furnace is of uniform temperature (temperature uniformity surveys should be carried out), a risk that some people do not take in consideration is when a component is placed close to the burners (flame impingement), this should be avoided at all costs.

Cooling down is also critical after the work is complete as this can change the grain size. Also if too high f a temperature has been used and the cool down is slow, you will see that the manganese sulphides will reduce in quantity but grow in size the longer it is left to cool.

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Reclamation of Overheated Steel

Overheated steels can probably be rescued by additional heat treatment. However this usually has a success rate of only around 60% when working towards a specific specification. Each treatment normally improves the mechanical test results but it can depend on what you are trying to achieve and whether is it viable to do so, due to the extra costs involved in the heat treatment operations.

The best method is to repeatedly normalise (six cycles minimum) the product at a slightly higher temperature then would normally be used, followed by a standard normalizing treatment. When performing this we recommend that all 6 cycles are carried out in one heat treatment lot. i.e. take it to the normalising temperature cool it well into the ferritic temperature range then increase the temperature to the normalising range and so forth. Holding at each set point for a period of time to ensure the material has equalised. Another option is to repeatedly harden and temper, including prolonged soaks and slightly elevated temperatures. This method does slightly improve the mechanicals but is not as effective as the normalising treatment described above.

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