3. Heat Treatment

Heat treatment does not find much use in structural fabrication so the discussion in this publication is brief. The process is always undertaken because it has one or more of the following effects:

- Softens cold worked materials
- Homogenises metals (removes composition gradients), particularly castings
- Removes residual stress
- Redistributes phases in multi-phase metals
- Changes the nature of metastable phases (eg harden and temper, age harden)
- Changes the surface chemical composition (case hardening)

Heat treatment is often used during material manufacture to optimise properties. Structural steels are commonly delivered in the normalised or thermo-mechanically controlled processed (TMCP) condition. Aluminium alloys are delivered annealed, cold worked or solution treated and aged, depending on the alloy. Austenitic stainless steels are normally delivered solution treated.

The only heat treatment commonly undertaken during fabrication of structural steel is stress relief. Even so it is rarely used and is not even addressed by AS 1554. A summary of the most used heat treatments follows.

3.1. Annealing

Annealing is a term that has different uses, depending on the material being heat-treated.

3.1.1. Removal of cold work

For most materials, annealing is used to remove the effects of cold work, restoring the material to its softest (lowest yield strength) and most ductile condition. This is done so that further cold work can be given, or for electrical conductors to provide optimum electrical conductivity.

This form of annealing is carried out above the recrystallisation temperature of the material, which is approximately 33 to 50% of the melting temperature in degrees Kelvin. After heating for a suitable time, usually 1 hour for each 25mm of thickness the material is allowed to cool. It is commonly used to soften a wide range of single-phase alloys that are strengthened primarily by cold working such as copper, brass, and some aluminium alloys.

For annealing to work, the material must have undergone a minimum amount of cold deformation. For steel, this is about 10% cold strain and aluminium 1%. As the amount of cold work is increased, more grains are nucleated and the grain size becomes finer.

The annealing temperature is important. If it is below the recrystallisation temperature, the amount of softening is limited. If it is too high, the grains grow in size, which reduces strength and ductility. Excessively high temperature can cause partial melting or cracking in some alloys. The ideal temperature depends on the alloy and the amount of cold work.

Depending on the amount of cold deformation the new grains can be finer than for the original unworked material. This finer grain size will have a marginally higher strength and ductility.

3.1.2. Process Annealing

If carbon steel is cold worked to more than 10% strain, it is possible to soften and restore ductility by annealing at about 500 to 600°C. At this temperature it is still ferrite.

3.1.3. Solution Annealing (Stainless steels)

Austenitic stainless steels are made homogeneous (composition gradients removed) by heating at a temperature of about 1080°C depending on the alloy. The steel is then rapidly cooled (quenched) to retain 100% austenite. If it cools too slowly ferrite or other detrimental phases can develop, embrittling the steel and reducing its corrosion performance.

3.2. Heat Treating Steels

Pure iron, carbon and low alloy steels undergo a solid phase transformation when heated. This gives steels the ability to have mechanical properties, particularly strength and ductility controlled by heat treatment. This allows steels to have a remarkably wide range of properties.

At room temperature, pure iron exists as a solid phase known as ferrite. If this is heated above 910°C, it transforms to new solid phase with different properties, known as austenite. When heating is continued above 1390°C austenite transforms back to ferrite. As the temperature is raised above 1535°C the solid ferrite transforms to liquid iron, (it melts). If the liquid iron is cooled, transformations from liquid to ferrite, ferrite to austenite and austenite to ferrite occur at similar temperatures. Ferrite that is stable between 1390°C and 1535°C is known as delta ferrite. Ferrite that is stable below 910°C is known as alpha ferrite.

The addition of alloy elements modifies the temperatures at which these phase transformations occur. This is best illustrated by the addition of carbon. As carbon is added in increasing amounts:

- The melting temperature is lowered, and instead of melting at a single temperature, it occurs over a temperature range.
- The temperature at which austenite transforms to delta ferrite is raised, and when the carbon level is above 0.1% delta ferrite only occurs together with austenite. Above 0.51% carbon delta ferrite does not occur at any temperature.
- The alpha ferrite to austenite temperature is reduced, and the transformation occurs over a range of temperature.
- The limit of solubility of carbon in ferrite is less than 0.02%. Excess carbon exists as iron carbide (cementite).
- The limit of solubility of carbon in austenite varies with temperature, but can be as high as 1.7%. Heating the steel to a temperature at which it transforms to austenite and all the carbon dissolves is the principle of a number of heat treatments.

The above effects are shown on a diagram known as the Iron–Iron Carbide Equilibrium Diagram, which is the key to heat treating steel.

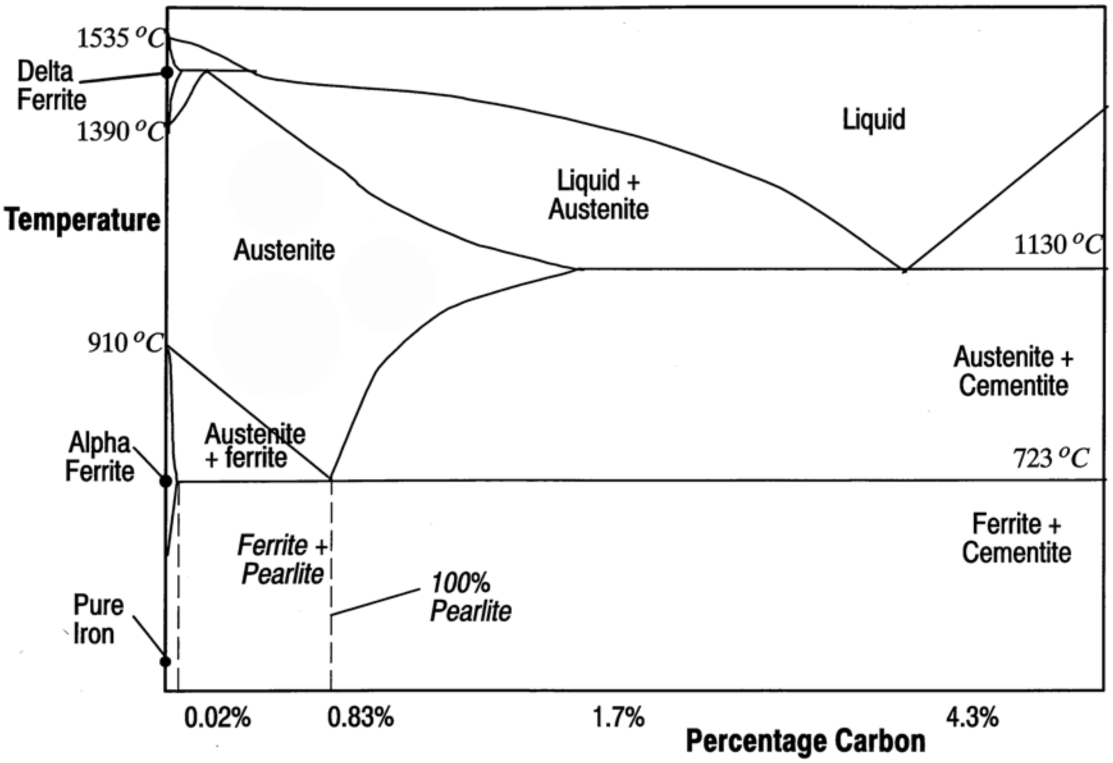

Figure 14 Iron - Iron carbide Equilibrium Phase Diagram

The iron–carbon diagram can also be used to explain the microstructure of steel, and thereby explain the mechanical properties. Structural steel contains up to 0.3% carbon, which is above the solubility in ferrite. The iron carbide in structural steel usually exists as a fine mixture with ferrite, known as pearlite. Cementite contains 6.67% carbon, and pearlite has 0.83% carbon. The more carbon the steel contains, the more pearlite. This raises strength but lowers ductility. A 0.2% carbon steel will have a structure of about 25% pearlite as islands surrounded by ferrite.

3.3. Annealing and Normalising Structural Steel

When steel is heated, pearlite transforms to austenite at 723°C or thereabouts. As the temperature is raised, the austenite dissolves more ferrite until above a critical temperature, it is completely austenitic.

The grain size of steel can be refined by heating to a temperature not more than 50 degrees above the temperature it becomes completely austenitic and cooling slowly. The original grains are replaced by fine austenite grains, which transform to fine ferrite and pearlite on slow cooling. If the steel is cooled in the furnace, it is fully annealed. If it is allowed to cool in still air, it is normalised. Note that no cold work necessary to perform this operation on steel.

Fully annealed steel has a microstructure of ferrite and pearlite. Normalised steel is similar except that the grain size is finer and the pearlite may be bainitic. Normalised steel has a higher strength and may be marginally less ductile than fully annealed steel.

AISC

An Engineer's Guide to Fabricating Steel Structures

Volume 1: Fabrication Methods

by John Taylor BSc, Sen.MWeldI

AUSTRALIAN INSTITUTE OF STEEL CONSTRUCTION
A.C.N. 000 973 839

AUSTRALIAN INSTITUTE OF STEEL CONSTRUCTION
A.C.N. 000 973 839

AN ENGINEER'S GUIDE TO FABRICATING STEEL STRUCTURES
VOLUME 1 - FABRICATION METHODS

NATIONAL LIBRARY OF AUSTRALIA
CARD NUMBER AND ISBN 0-909945-88-8

Published by:
AUSTRALIAN INSTITUTE OF STEEL CONSTRUCTION

FIRST EDITION 2001

National Library of Australia Cataloguing-in-Publication entry:

Taylor, John Stuart.
An engineer's guide to fabricating steel structures. Volume 1,
Fabrication methods

Bibliography.
Includes index.
ISBN 0 909945 88 8 (v. 1).

ISBN 0 909945 89 6 (set).

1. Building, Iron and steel. 2. Welding. 3. Steel, Structural.
I. Australian Institute of Steel Construction.
II. Title.

624.1821

Set
ISBN 0-909945-89-6
9 780909 945893

Production by Redmark Pty. Ltd.
6 Kuru Street, North Narrabeen, NSW 2101, Australia

Enquiries should be addressed to the publisher:
Australian Institute of Steel Construction
Business address - Level 13, 99 Mount Street, North Sydney, NSW 2060, Australia.
Postal address - P.O. Box 6366, North Sydney, NSW 2059, Australia.

Disclaimer:

Contents