Welding Technology – Module 4

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METALLURGY

A palm oil mill engineer must understand basic welding metallurgy because it enables him to control two most important aspects of welding technology, *i.e.:*

- the chemistry and soundness of the weld metal; and
- the microstructure of the weld metal and the heat affected zone (HAZ) of the base metal.

Metallurgy consists of:

- process metallurgy; and
- physical metallurgy.

Knowledge of basics of welding metallurgy is necessary for the welding engineer, since the mechanical properties of a metal such as strength, hardness, ductility, toughness, fatigue and abrasion resistance are all effected by the metallurgical transformation caused by welding.

MICROSTRUCTURAL CONSTITUENTS OF CARBON STEEL

The overall arrangement of grains, grain boundaries and phases present in the metallic alloy is called: microstructure. The microstructure is primarily responsible for the properties of the alloy. The microstructure is affected by the composition or alloy content. Other factors, thermal cycle of welding greatly affects the microstructure, which in turn change the properties of the alloy.

Microstructural Changes Due to Welding

The microstructural changes due to welding are caused by significant changes in the temperature of metal and the rate of cooling from the elevated temperatures. Within the weld, from the region of the highest temperature, the metal cools down from liquid through various phases as mentioned earlier.

Heat Treatment of Steel

The process of welding involves heating and cooling of the base metal. This thermal cycling can have an impact on the properties of the HAZ. The effect of the welding heat on the HAZ depends on the:

- composition of the base metal;
- heating rate and cooling rate of the HAZ; and
- welding procedure used.

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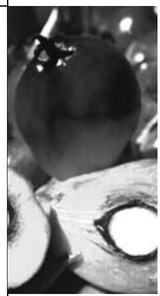

Annealing

In this, the temperature of a component is raised to about 850°C in the furnace and cooled very slowly. Slow cooling is achieved by putting off the fire from the furnace with the component inside so that the component cools down at the same rate as the furnace. The annealed component is very soft and ductile.

Normalizing

This is done to refine the grain structure to improve the machining ability. The strength is achieved by heating the component to austenite temperature of about 850°C depending on the composition and cooling it in still air. A normalized component is harder and stronger than fully annealed component. The hardness depends on the carbon and alloy content.

Hardening

In this process, the steel is heated to austenite temperature and cooled rapidly. This results in the formation of hard and brittle martensite. Fastest cooling is achieved by immersing the hot component in a solution of water and salt (brine). Plain water gives slightly slower cooling rate. Quenching in oil results in still slower cooling rates.

Tempering

This is an essential operation carried out after hardening. The basic purpose is to reduce the stresses formed during the formation of martenasite and to improve the toughness of martensite. The process consists of heating carbon steel, which has already been hardened to at least 160°C and keeping at that temperature for a minimum period of 30 min and then it is cooled. The tempering temperature in any case does not exceed 650°C.

Case Hardening

This process is adopted when a hard surface for wear resistance is required. The core is soft and tough to withstand the impact and improve the fatigue properties. There are two methods of case hardening. Heating of the surface and cooling it rapidly so that martensite is formed on the surface while the core remains unaffected.

Flame Hardening

In this process, the surface of the part is heated by flame to about 850°C and immediately cooled in water. The steel must have sufficient carbon or alloying element to form martensite on cooling. The surface hardness achieved can vary from 35 RC to 50 RC depending on the composition.

Induction Hardening

The difference between flame and induction hardening lies on the source of heat. In induction, hardening is the current induced on the surface of the job and gets it heated. The coil can be designed based on the shape and size of the component to have faster rate of production. The increase in the frequency of power supplied will reduce the depth of hardening in an induction hardened part. Thus, it is possible to have much greater control over the depth of hardening changing the chemical composition of the surface.

Case Carbonizing and Hardening

In this process, low carbon steel (0.2% carbon) is selected and carbon on the surface is increased by heating the part in a carburizing medium. The surface carbon after carburizing will be 0.8%. The part is hardened and tempered at around 180°C. This results in the formation of high carbon martensite on the surface. The hardness on the surface is 60 RC and the core hardness

in a fully martensite structure will be 30 RC. The depth of hardness varies from 0.5 mm – 2.5 mm.

Nitriding

In nitriding, nitrogen is added to the surface. The steel used for nitriding contain aluminium (1%) and form a very hard aluminium nitride with a hardness of about 68 RC. The steel is normally hardened and tempered at 600°C before nitriding. The carbon content of steel is around 0.4% and core hardness is about 300 BHN. The depth hardness is much lower than that produced by carburizing. Nitriding process is for extreme wear resistance.

PRE-HEATING

For welding of medium carbon steel, low alloy steel, high alloy steel and high carbon steel, certain amount of pre-heating is required. Pre-heating is the heat applied to the substrate before welding. The amount of pre-heating recommended is given by the following formula for carbon equivalent present in the steel:

$$Ce: \%C + \frac{\%Ni}{20} + \frac{\%Mn}{15} + \frac{(\%Cr + \%Mo + \%V)}{10}$$

If Ce < 0.30 % - no pre-heating is necessary.
If Ce > 0.30 % - pre-heating is necessary.

What is Heat Input?

Heat input is the arc energy or electrical energy charged into the weld metal in a unit time.

$$\text{Heat input} = \frac{\text{Voltage (V) x Current (A)}}{\text{Speed (mm } s^{-1}\text{) (1000)}}$$

Effects of Pre-heating

- Reduce the quenching effect;
- Reduce the maximum hardness at HAZ;
- Removal of moisture and hydrogen;
- Welding arc is stable in heated environment;
- Improve fusion and melting; and
- Reduce the occurrence of cracking.

When to Pre-heat

Too low ambient temperature for welding. It is required by several codes to pre-heat the substrates to at least 21°C for welding.

- Dampness in the base metals - moisture being harmful for welding has to be removed.
- Increased plate/pipe thickness - it is necessary to reduce the cooling rate and retain the heat in the weld zone.
- Rise in carbon content or CE carbon equivalent percentage in steel. It is required to retard the rate of cooling for reducing the hardening and hydrogen absorption in HAZ.
- Increase the degree of restraint or cooling stresses. The level of residual stresses in the weld have to be reduced.

How to Pre-heat

- Pre-heat with gas torches, electrical resistance heating, heating blanket or heat treating furnaces;
- The pre-heating temperature and the length of pre-heating time depend on the method of pre-heating;
- The pre-heating should be done uniformly and maintained though the cross-section of the substrate; and
- The pre-heat temperature is measured just prior to welding. Time lapse of 15 s is often recommended.

Interpass Temperature

Interpass temperature is the temperature maintained during welding and between the runs of welding to obtain desired metallurgical structure. The interpass temperature should drop below or exceed

the pre-heat temperature.

Post-weld Heat Treatment

Post-weld heat treatment (PWHT) is the application of heat after welding. It is a process in which the weld metal in solid state is subjected to one or more controlled heating and cooling cycle after welding. It is normally carried out for stress relief and reduction of localized residual stresses induced during the welding operation into the metal.

The Variables of PWHT Process

- The rate of cooling;
- The uniformity of heating;
- The temperature of heat treatment;
- The soaking period at the heat treatment temperature; and
- The mode of cooling, the rate of cooling.

PWHT may also be used to modify certain properties such as:

- softening the metals after cold working;
- hardening the metals to produce improve strength and hardness;
- tempering the metals to improve hardened structures giving range of toughness and strength; and
- hydrogen removal.