Flame Hardening Metallurgical Process for Surface Hardening of Steel Components

B.V.R.RAJA
Senior Manager (Quality Assurance), Alloy Steels Plant, Steel Authority of India Ltd., Durgapur

Introduction

Flame hardening is a surface hardening process to harden the specific surface areas of a steel component to withstand abrasion and wear with reasonable toughness of the unhardened core improving fatigue, bending & torsional strengths. It involves heating the component surface to the austenising temperature with combustible gas flame followed by quenching and low temperature tempering. The objective of this hardening method is to provide a hard martensitic layer on specific surface areas of the work piece, improving the mechanical properties, without affecting the remainder of the part. The hardened depth in this process could be 0.8 mm to 7 mm or more depending upon the gas mixture for heating, the design of the flame head, heating duration, quenching medium, method of quenching and hardenability of the steel.

The heating medium for flame hardening is a mixture of oxygen (or air) and a combustible gas mainly acetylene, natural gas, propane or propylene. Out of the above, oxy-acetylene gas mixture has high flame temperature with a thin layer of 3 mm at the surface of the component is rapidly heated to a temperature above the critical and then quenched by the double action of a water spay upon the surface and the conduction of the heat into the cold base metal. Along the surface layer, the normal pearlitic structure of the steel is first converted to austenite in passing through the critical temperature range, but rapid quenching prevents the reverse process and the steel layer is held in a martensitic state which is the hardest state possible for steel, offering a surface protection without affecting the main body. The remainder of the part retains its original toughness. For deeper case depths, air-fuel gas mixtures or oxy-fuel gas other than acetylene are commonly used as these provide lower flame temperatures. It is the rate of heating, the cost of gas and the case depth that determines the right gas mixture. Because the parts to be hardened may be round, flat or irregularly shaped, the mechanical arrangement and the movement of the flame varies in accordance with the shape of the part being treated. In general, slower the rate of flame travel, the greater the heat penetration and the hardening depth. Here, the burner design is very important with burners made of copper or brass are shaped to conform to the component curvature to be treated into drilled parts or inserted tips to direct flame on the localized regions to be hardened. The flame heads may be fitted with screw in or inserted variety orifices for gas flow with designs that consider ideal proportions among pre-heat, fuel gas orifices and mixing chamber dimensions to provide more stable out coming flames that gives high resistance to backfire, flame pops and flashback.

For temperature measurement, various devices such as digital infrared pyrometers are available in the market. After heating the component surface by flame to the requisite temperature, the part is quenched. The quenchants for spray quenching can be water, brine solution, polymer or air and caustic or brine solution, water, oil or polymer for immersion quenching. It is the type of steel, the hardness, the depth of hardness and the product geometry that determines the right type of quenchant. The design and the positioning of the quenching jet has a profound influence on the effectiveness of flame hardening. For drastic and effective immersion quenching, the hot work piece should be brought to the quenching medium immediately. One can incorporate quenching jets in the heating tip itself with no interference of quenching jets with the heating operation.

The components after flame hardening necessitate tempering treatment to relieve the stresses generated during hardening. For large components with hardening depth of 5mm or more, the residual heat present after quenching is sufficient enough to take care of stresses generated during hardening by self tempering. In majority of the components, the heat diffused from the Heat affected Zone is not desirable as it results in crack formation. How ever, tempering treatment at 150?C - 200?C depending on the grade of steel is necessary which can be carried out either in oil bath, salt bath or flame heating again followed by air cooling. Holes , keyways, thin sections, reliefs and changes in section in the heat affected zone increase the risk of distortion and/or cracking and if possible these details should be machined after flam hardening.

The versatility of flame hardening makes it a natural for applications which must provide surface protection for parts that may be curved or straight, light or heavy, or cannot be economically hardened by other methods whether the parts are large, small or intricate. It finds suitability for such applications where only the surface or selective areas require heat treatment thus, maintaining good dimensional stability while the treated areas have their properties selectively improved. The applications include shafts, shaft journals, gears, cams, cast bed ways, crane wheels, punches, rails, rope drums, sheaves, dies, wear pads, splines, sprockets, machine components, chuck jaws, connecting rods, pins, bushes, guides, rollers, blades, piston rods, injector screws, crushers and a variety of tooling.

Operating Variables for effective Flame Hardening

The various operating variables that necessitate proper control for effective flame hardening of steels include

1. Grade of steel and its prior micro - structure
2. Skill of the operator
3. Gas mixture used for combustible flame
4. Velocity of the flame
5. Distance between the flame and the component surface
6. Speed of the flame head travel or the component
7. Type of quenchant and the angle of quench

Steel Selection for Flame Hardening

The aim of heat treatment of steel is very often to achieve a satisfactory hardness. The important microstructural phase is normally martensite, the hardness of which primarily is dependent on its carbon content and the maximum hardness that can be produced in any given carbon steel is that associated with a fully martensitic microstructure. The high hardness and associated high strength, fatigue resistance, and wear resistance are the prime reasons for applying the quenching heat treatments that produce martensite. Hence, it is mandatory to apply flame hardening for steels containing more than 0.3% carbon and preferably more than 0.40%, in which the gains in hardness are most substantial.

There are other elements which affect the hardening process such as manganese, chromium, molybdenum, nickel and silicon, but carbon is by far the most influential. The final surface hardness achieved depends on the chemical composition of the steel, the quenchant used (air, water, oil or polymer) and the section thickness of the component.

The common steels applied for flame hardening, the case depth obtained and typical applications are listed in Table 1 below.

Steel Grade	**Hardening Temperature (□c)**	**Maximum Surface**	**Case Depth(mm)**	**Typical Applications**
AISI 1045	860-900	50-60	3.2	HARDNESS (Rc) Gears, spindles, pinions, guide ways, cam shafts , gudgeon pins
AISI 1055	835-865	55-62	3.2	Lathe spindles, guide ways, tailstock sleeves, gudgeon pins, worm shafts, gear shafts
AISI 1060	820-850	58-65	3.2	Tools for machining industry
AISI 4140	860-890	50-55	4.8	Highly stressed components like pinions, crankshafts, gear shafts
AISI 5140	860-890	50-55	4.8	Highly stressed components like shafts, crankshafts and parts of machining shafts
AISI 6150	860-890	55-60	4.8	Components subjected to heavy loads with oscillating or impact loads such as gears, drilling rods, dredger pins
AISI 8640	850-880	50-55	4.8	Very highly stressed components like gear shafts, gears, pinions

Table.1

All the above steels are either water sprayed or oil quenched after heating to the temperatures mentioned followed by low temperature tempering at 150?C - 180?C. Other steel grades such as AISI 4150, 4340,En25, En 26, K245 tool steel and martensitic stainless steel (400 series) may be successfully flame induction hardened.

Treatment of Steels prior to Flame Hardening

The input steel products of carbon steel should be subjected to normalizing treatment to get fine grain structure. For more then 0.55% C steels, normalizing followed by tempering should be carried out. For alloy steel products, annealed structures are desired. The products must be free from scale,rust, decarburization, lap, fold, seams, crack, oil, dust and be ultrasonically sound before subjecting to flame hardening operation.

The steel components after heavy machining need to be stress relieved at about 550?C-600?C for about 1-2 hrs followed by air cooling to release stresses generated in machining and help in avoiding distortion or cracking during flame hardening especially in high carbon steels and alloy steels.

Processes of Flame Hardening

These processes are broadly classified as Stationary, Progressive, Spin and Combined progressive-spin flame hardening. The method chosen depends on the steel grade, component geometry & the specified surface areas to be hardened.

Stationary Or Spot Hardening

In this method, both the flame and the component are held stationary. The flame is directed to the spot that needs to be heated and hardened. Here, localized heating of the component surface is carried out by welding torch held with hand or flame head with single or multiple orifices to the austenising temperature with sweep movements of the flame head for ensuring uniform temperature. After this, the component is taken to the quench or quench is brought with quenching carried out in water or oil depending on the chemical composition of the steel as shown in Fig.1.

Fig.1. Stationary Flame Hardening Of Gear Followed By Quenching In Oil

It is particularly adopted for shaft ends, large gears, bolt heads, special steel casting configurations and large parts.

Progressive Hardening

This process involves the use of a flame head usually of multiple orifice with or without integrated quench capability that traverse the surface of the component to be hardened. Here, the flame head and quench head is mobile and moves across the surface of the component to be hardened. The surface to be hardened is scanned, heated progressively with flame head mounted on a moving carriage running on a track followed by immediate quenching at a uniform speed with speeds ranging from 0.8-5 mm/sec depending on the desired depth of hardness. Generally, the quenching is carried out by water spray integrated with the flame head leading to uniform heating and spray quenching to produce flame hardened surface free from soft spots.

This method is particularly suited for hardening guide ways, lathe beds, knives and flats as is shown in Fig.2.

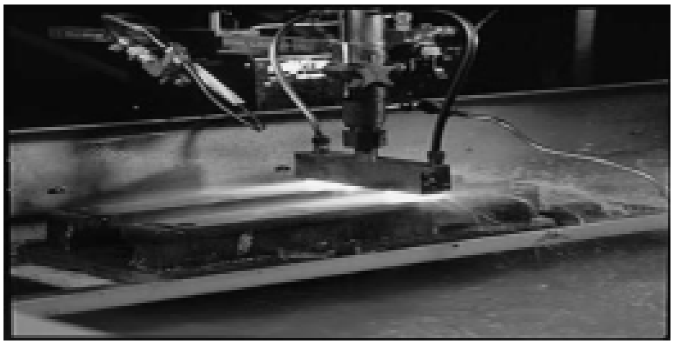

Fig.2. Progressive Hardening Of Guide Ways

Spin Hardening

In this method, the component is surrounded by the stationary flame heads and heated to the desired hardening temperature while being spun rapidly. After reaching the temperature, it is lowered into, or sprayed with, the appropriate quenching media. The process is shown in Fig.3 finding suitable for hardening gears below 100 mm

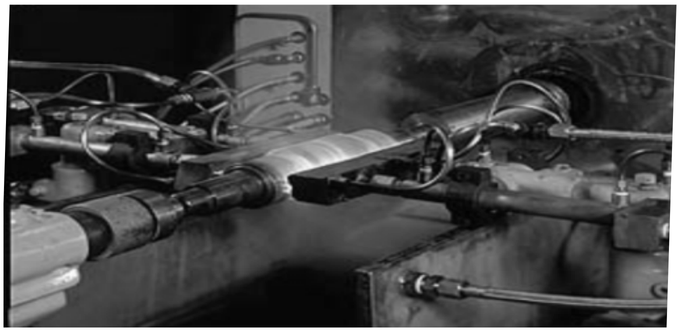

Fig.3. Spin Hardening Of Gear Teeth On Worm Shaft

diameter, hubs, shafts, wheels and sprockets.

Combined Progressive-spin Hardening

This technique combines both progressive and spinning methods to provide uniform heating and quenching of a rotating part. The process involves progressive heating along the axis of the spinning component with spinning at 75-300 mm per minute followed by quenching by water jet tangentially upon rotation of the component. Here, flame head and quench jet are both fixed to a carriage that traverse along the component as shown in Fig.4. The process is generally adopted for hardening rolls and shafts.

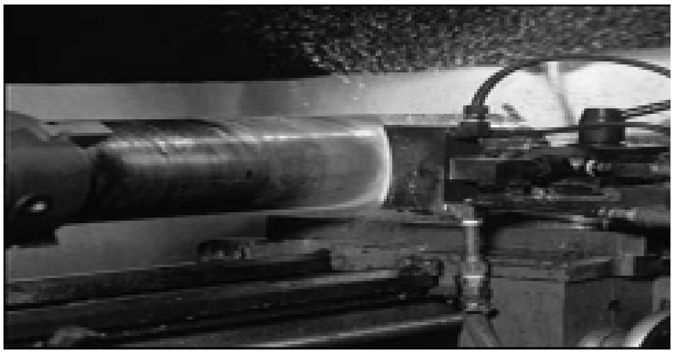

Fig.4. Combined Progressive-spin Hardening Of Large Diameter Shaft

Conclusions

Flame hardening process incurs benefits such as application for a wide variety of steels with no restriction on size and shape of the component, selective hardening of surface areas in a component with wide depth of hardness, facilitates use of cheaper carbon steels over alloy steels with similar properties, faster than carburizing & nitriding treatments and highly economical for large component hardening compared to conventional heat treatment. The major drawbacks include process standardization for a component to be hardened depending upon the facilities available, difficulty in control of case depth and of course, high safety precautions to handle the explosive gases.