DESIGN FOR HEAT TREATMENT

Heat treatment is a property enhancing operation. It is secondary in sequence to other parts-making operations. Property enhancing operations are performed to improve mechanical or physical property of the work material. They don't alter material part geometry. Heat treatment involves various heating and cooling procedures performed to affect the micro-structural changes in a material, which in turn affect the mechanical property of the work part. This heating (and eventual cooling to room temperature) either softens the material or hardens it. The results of this process depends, on

1. Specific material
2. Temperature to which the material is heated
3. Method and rate of cooling

As the number of heat treatment processes is large and the details of each process are infinite, it is impossible for a designer to know every property enhancing process. The designer should be aware of the general types of heat treatment processes available and know enough of their details so that they can make reasonable decisions as to how their parts should be heat-treated.

Heat treating process for steel

Softening processes

Stress relieving: Due to various mechanical cold working processes like rolling, forging, drawing etc. an internal stress is developed inside the material. This stress is reduced by heating the part to some point below the critical temperature and then allowing the material to cool slowly to room temperature which produces some micro-structural changes in the material.

Annealing: Annealing is a process of heating the metal to a temperature above the austenizing temperature for sufficient time as long as the material transforms into austenite or austenite-

cementite & then cool slowly at the rate of about 20ºC/hr. Annealing is performed to improve the ductility of material so that it can be mechanically processed more easily by other processes.

Normalizing: This process is slight different from annealing. The process of annealing consists of heating the metal to a temperature above the austenizing temperature, holding at that temperature for certain time, but it is allowed to cool in air at a faster rate. The resulting structure is uniform but not as soft as fully annealed.

Hardening processes

Hardening is the process of heating the material to a temperature above the austenizing temperature until all pearlite is transformed into austenite, and then quenching it rapidly in water or oil. The temperature at which austenizing rapidly takes place depends upon the carbon content in the steel used. Depending upon the required hardened structure, different heating & cooling operations are performed subsequently.

***Surface hardening*:** Surface hardening refers to any of the several thermo-chemical treatments applied to steels in which carbon or nitrogen must be diffused into the surface at an elevated temperature and then the work piece is cooled at a rate sufficient to harden the surface. The term case hardening is used for surface hardening. Four methods used are carburizing, cyaniding, nitriding, and carbonitriding. The name suggests the type of material to be diffused.

Through hardening: This is achieved by heating the part uniformly for a long time to a point above the critical temperature and finally quenching it in an appropriate medium. To provide necessary cooling rate required to harden the part, generally water, oil, or air, with varying degrees of agitation are recommended to be used. The grade of steel & the size and shape of the part also affects the selection of quenching medium.

Martempering: It is a common heat treatment process that quenches the material to an intermediate temperature just above the point at which martensite starts and then allowed to cool slowly thereby, providing through-hardened structure with less distortion.

Austempering: In this process, the part is quenched directly into a liquid salt bath at a temperature between 590˚ to 710˚ Fahrenheit to transform the Austenite into Bainite. The part is

then removed from the salt quench and air cooled to room temperature to produce higher ductility.

Note: Interested reader can refer heat treatment process for other ferrous metals such as cast iron, stainless steel etc. and nonferrous metals and their alloys such as copper and copper alloys, magnesium alloys, nickel and nickel alloys, aluminum and aluminum alloys, titanium and titanium alloys etc.

Characteristics and applications of heat-treated parts

Case-hardened steel parts:

These parts are produced by carburizing the component's surface, then quenching and tempering the part. To achieve extra strength, hardening of the core is incorporated. Commonly used case depths are 0.025 to 1.5 mm, and case hardness ranges up to Rc65. This combination of properties provides wear resistance and fatigue strength at the surface, and impact strength in the core.

Surface-hardened steel parts:

These parts are produced by carburizing the component's surface by using a thicker layer of hardened surface material & then heat treated to attain higher strength & higher wear resistance with lower surface distortion. The thicknesses go up to 6.3 mm. Typical surface-hardness values for these parts range between Rc40 and Rc60. Flame and induction surface hardening are frequently used for local hardening of parts.

Through-hardened steel parts

These are produced by heating the part uniformly for a long time to a point above the critical temperature and finally quenching it in an appropriate medium to produce parts with maximum physical properties i.e. yield strength of steel is greatly increased which is used in high-stress, high-strain applications. Examples of through-hardened parts include metal springs, dies, molds, and various machine parts subjected to high loads.

Hardened Cast-Iron Parts

These cast irons parts are produced mostly by flame hardening process which provides higher strength and wear resistance. The carbon & alloy content of the austenite affects the hardness of the cast-iron parts. By the help of tempering process at lower temperature, the strength & toughness of iron parts increase.

Stainless Steel Parts

After the fabrication of stainless steel, it undergoes a heat-treatment process to reduce the residual stress level by improving the mechanical properties & corrosion resistance. The precipitation-hardening of semi austenitic steels helps in improving the tensile strengths up to 1310 MPa. The annealing process of ferritic and austenitic stainless steels help in restoring the ductility and softness after work hardening process and it also helps in improving the maximum corrosion resistance.

Copper-Alloy Parts

Parts fabricated from the mill need not require further treatment other than stress relief to remove the manufacturing stress because it is already supplied in the solution-treated or age-hardened form. Parts fabricated from solution-treated material must be age-hardened. During age-hardening process, close control of parts by using fixture is required because some copper–alloys like beryllium copper distort in the direction in which they were plastically formed or elastically deflected.

Aluminum-Alloy Parts

Generally the supplied aluminum-alloy parts are solution treated & precipitation hardened, which reduces the ductility of parts by improving the tensile & yield strength and hardness. So, it requires annealing process to improve the ductility which helps in providing easier fabrication with forming methods.

Selection of material

It is recommended to use common materials that will produce improved physical properties and would be easily available at reasonable cost. Further, it is essential to have the knowledge of

what is required for heat treatment and the expected results on the specific part under consideration. This would again provide a limited number of grades from which a final determination has to be made.

Low-carbon steel

Due to the case hardening heat treatment process, the low-carbon steel (up to 0.25 percent carbon) produces a hard, wear-resistant surface.

Medium-carbon steel

The medium-carbon steels (0.25 to 0.55 % of carbon) are generally produced by through-hardening & tempering process which provides higher tensile strength ranging from 690 to 1380 MPa. Due to the lower strength of low carbon steels, designers opt for high strength medium-carbon steels. It is widely used in parts requiring medium strength and high toughness.

High-carbon steel

Due to the higher percentage of carbon, the high-carbon steel (0.55 to 1.00 percent carbons) has higher strength, hardness, higher fatigue & abrasion resistance. Due to difficulty in fabrication and higher cost, it is rarely used.

Alloy Steels

Generally, alloying elements are added to plain carbon steels to provide various improved properties like (1) better strength in larger sections (2) less distortion during hardening (3) higher resistance to abrasion keeping the hardness same (4) higher toughness at the same hardness in small sections or (5) greater hardness and strength at elevated temperatures. To achieve these properties (one or more), it is required to carry out the following: (1) changing the hardening characteristic, (2) changing the nature and amount of the carbide phase of the steel (3) changing the tempering characteristics.

When alloying elements (expect cobalt) are added to steel, a higher hardenability is achieved. Hardenability provides the measure of the depth of hardening produced by quenching.

Cast Iron

The combined carbon content in gray cast iron is one of the major determining factors in flame hardenability. Generally alloy gray iron ranging between 0.50 and 0.70 % is more prone to flame hardening process than unalloyed gray iron because of wider temperature range & greater martensitic depth.

Stainless Steels

Heat treatment of stainless steels is mostly carried out under controlled conditions to avoid carburization, decarburization and scaling on the metal surface. The carbon content affects the maximum strength and hardness of material. Austenitic stainless steels can be surface hardened by nitriding.

Copper and Copper Alloys

Stress relieving, annealing, solution treating and precipitation hardening are the various heat treatment process i.e. applied to copper & copper alloys. Aluminum bronze, Beryllium copper, Copper-nickel-silicon, and Copper-nickel phosphorous are produced by precipitation hardening process.

Distortion

Due to the heat treatment process, a considerable improvement in physical properties occurs along with some undesirable changes in size & shape. These changes in dimensions occur mainly due to the various stresses (i.e. thermal stresses, stresses developed by the transformation of hardened structure etc.) that are developed by the manufacturing operations. Further, some distortions are also developed during the handling of heat treatment processes at the austenizing temperature which is more intensified due to rapid heating and cooling. (See Figure M5.7.1)

Arrows show direction of stress. (a) Part heated uniformly throughout. Center area and surface both are expanded. (b) Start of quench; surface contracted more than center. (c) Midway during quench; surface transformed, center contracting. (d) Near end of quench: surface cold and rigid, center transforming and expanding. Dimensional changes and distortion in the case of case-

hardened parts are dependent on (1) configuration of the part (2) the process used (3) previous stresses in the part (4) grade of steel used.

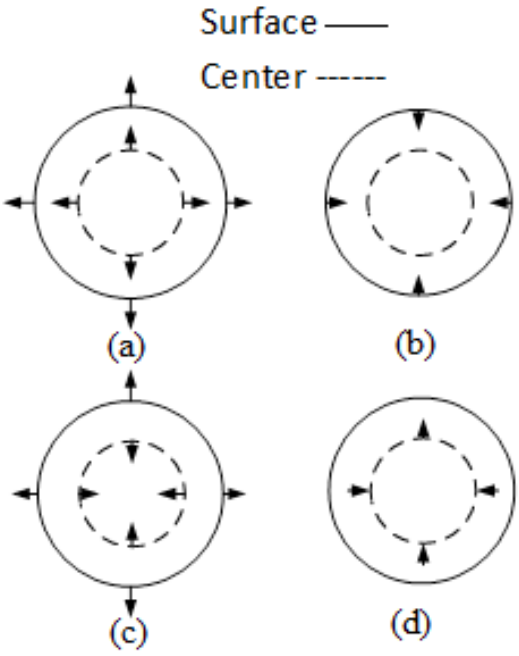


Figure M5.7.1: The distribution of stresses in a typical part during heating and quenching.

However, the amount of distortion is also dependent on the design, no matter which method is used. These distortion can be controlled by simple change in the way in which the part is handled or using a completely different method. For example, suppose a case-hardening method causes high distortion for a given part, then the heat treater must select a less severe method like cyaniding to produce the specified results.

Design recommendations

The recommended principles to achieve a good design for heat treatment are:

- Required properties in the heat-treated part need to be achieved without allowing the part to be distorted beyond the acceptable limits
- Heat-treated part resist external stresses during service without failure.

  Keeping the above principles in mind, the following design recommendations need to follow for heat treatment.

1. General rule is to make the part as simple as possible, keep it symmetrical, have uniform cross-sections, and balance the weight.

2. Abrupt changes in sections of parts to be heat treated need to be avoided (See Figure M5.7.2)

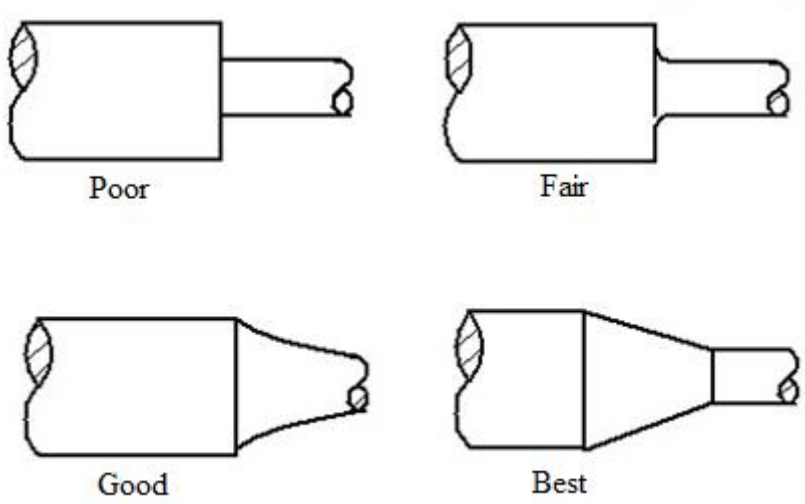


Figure M5.7.2: Avoid abrupt changes in sections of parts to be heat-treated.

3. Rounded, symmetrical cross-section reduces heat treating stress. Long, thin parts (such as connecting rods) should have symmetrical, rounded cross sections to reduce stresses. (See Figure M**5.7**.3)

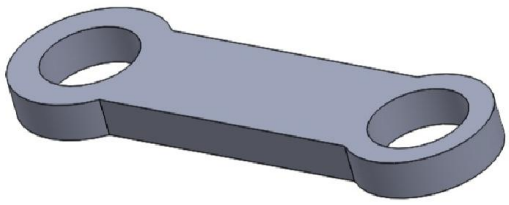


Figure M5.7.3: Rounded, symmetrical cross sections reduce heat-treating stresses.

4. In symmetrical cross-sections parts having holes, it is always recommended to place the hole at the center of the part so that the mass of metal surrounding them is equally balanced. (See Figure M5.7.4)

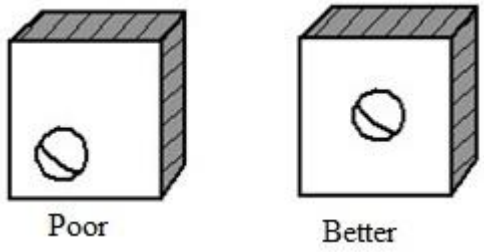


Figure M5.7.4: Maintain uniform section thickness around holes.

5. The location of holes or cutouts should not be located closer than 1.5 times diameters from the edge in order to avoid unequal mass distribution. (See Figure M5.7.5)

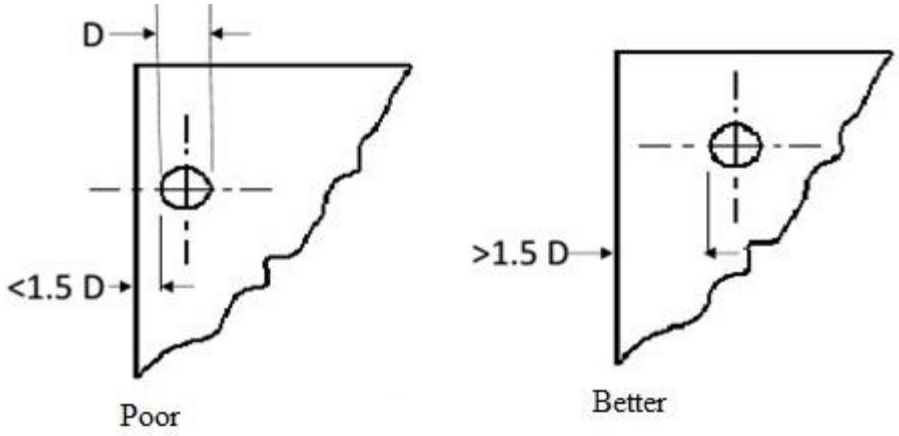


Figure M5.7.5: Minimum spacing from edge to center of hole should be 1.5 times diameters.

6. Sharp internal corners, generally concentrate heat treating stresses and hence need to be avoided. It is recommended to have all internal corners as round, and non-cutting holes should have radii at the top and bottom surfaces.(See Figure M5.7.6)

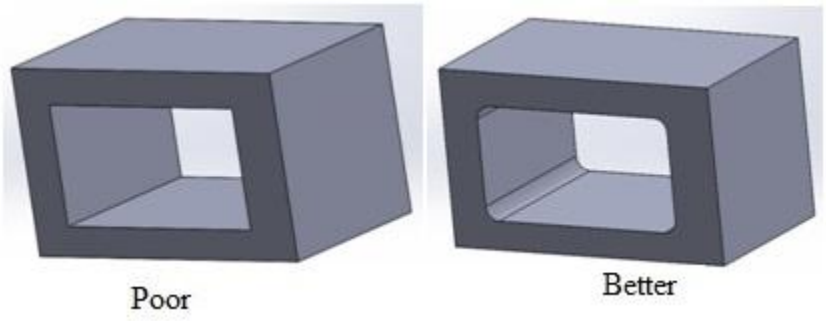


Figure M5.7.6: Avoid sharp internal corners, which concentrate heat-treating stresses.

7. Sharp edges at the entry and exit edge of the hole need to be avoided and it is preferred to provide radii at the top and bottom surfaces.(See Figure M5.7.7)

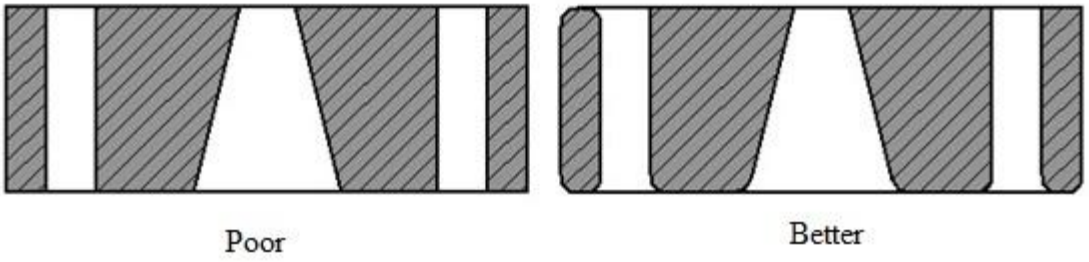


Figure M5.7.7: Smooth (radius) surface at entry and exit edges of holes.

8. Press-metal dies are usually heavy, flat sections designed to resist high stresses during operation and these need extreme precision after hardening. Die section should have balanced mass to avoid heat treating problem.(See Figure M5.7.8)

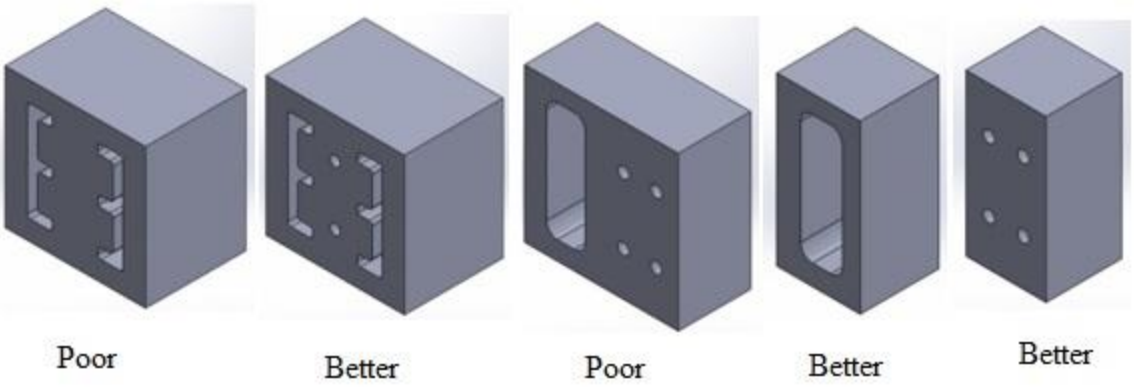


Figure M5.7.8: Die sections should have balanced mass

9. Section width of the die around large openings should be twice the thickness of the die block (See Figure M5.7.9).

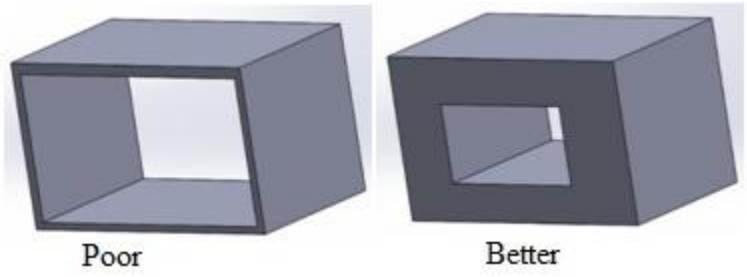


Figure M5.7.9: Minimum section width is around two times stock thickness.

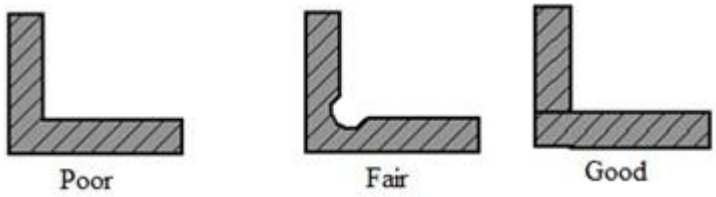


Figure M5.7.10: Two-piece construction for internal corners.

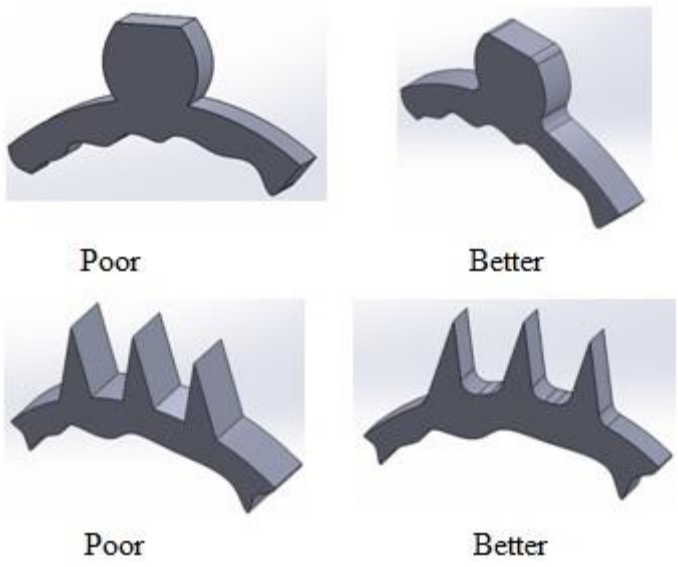


Figure M5.7.11: Rounded corners at the base of gear and ratchet teeth

10. The two-piece construction is advisable to eliminate the stress concentration in internal corners for a die section which is having unbalanced sections or irregular in shape. (See Figure M5.7.10).

11. Individual teeth should have ample radii at the root and edges to avoid to thermal stresses (See Figure M5.7.11).

12. Teeth should be located properly to avoid thin sections.

13. Keyways, whether external or internal, should have generous radii and be located symmetrically. Keyways used with gear or cutter teeth should be positioned in line with the base of the tooth so as to maintain uniform cross-section.

14. The hub of a gear is subjected to distortion in case of unbalanced mass. Generally a sectional design is considered for a function which requires unequal mass distribution. (See Figure M5.7.12).

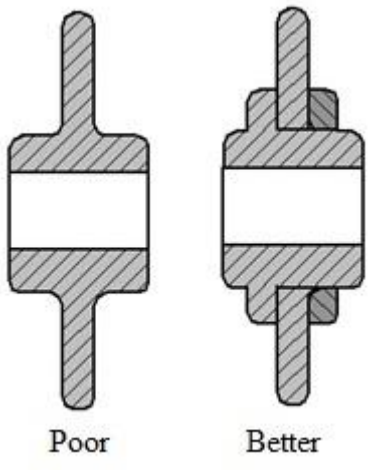


Figure M5.7.12: A sectional special sprocket or gear design

15. Parts with through holes concentric with the axis provide more uniform section thickness and reduce heat treating problem such as distortion. (See Figure M5.7.13).

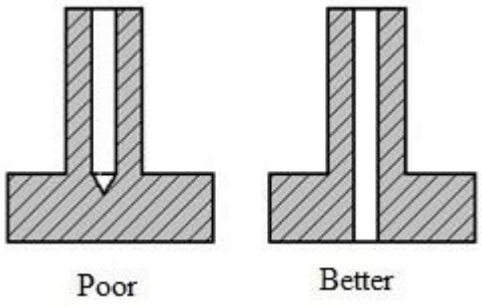


Figure M5.7.13: Right side through holes provide more uniform section thickness.

16. It is recommended to specify the desired end condition in the drawing rather than the process to maintain same standard.

17. The total case depth or effective case depth is required to specify case hardening. If the part is to be ground, it is to be stated whether the depth applies before or after grinding. In case depth and hardness, it is required to provide tolerance as liberal as possible.