Materials for Automobiles

Lec 7

24 August 2011

Surface Hardening

Induction Hardening

Purpose	Ensure : Hard wear and fatigue resistant case Tough core There are major savings in power and also in material movement during process.
Components	• Crankshaft • Camshaft • Stub axle • Axle shaft • Gears and gear box shafts • Propeller shaft spline yoke/ shaft
Common steels	medium (0.3% to 0.5%) Carbon steel Alloy additions depend on the core properties required. Sulphur content has to be low.
Process	Core: desirable core structure to meet strength requirements can be achieved by either normalizing or by hardening and tempering Case : Case depth and hardening is achieved by induction heating and followed by quenching of the surface only. After this tempering is carried out.
Properties achieved	Case Hardness :45- 58 HRc Case Depth : 1.5-12.0 mm (typical) Core hardness : 150 - 360 HV10

Induction hardening process (Typical)

	Temperature˚C	Time Hrs	Details
Degreasing	80-100	0.25	
Harden	OQ from AC3 810-840	1 to 2	
Degrease	80-100	0.25	
Temper	550- 600	2 hrs	
Clean if required			
Induction harden	Only power is set	For 30 seconds	Water/ polymer quench
Temper	180 - 200	2 hrs	

Induction Heating

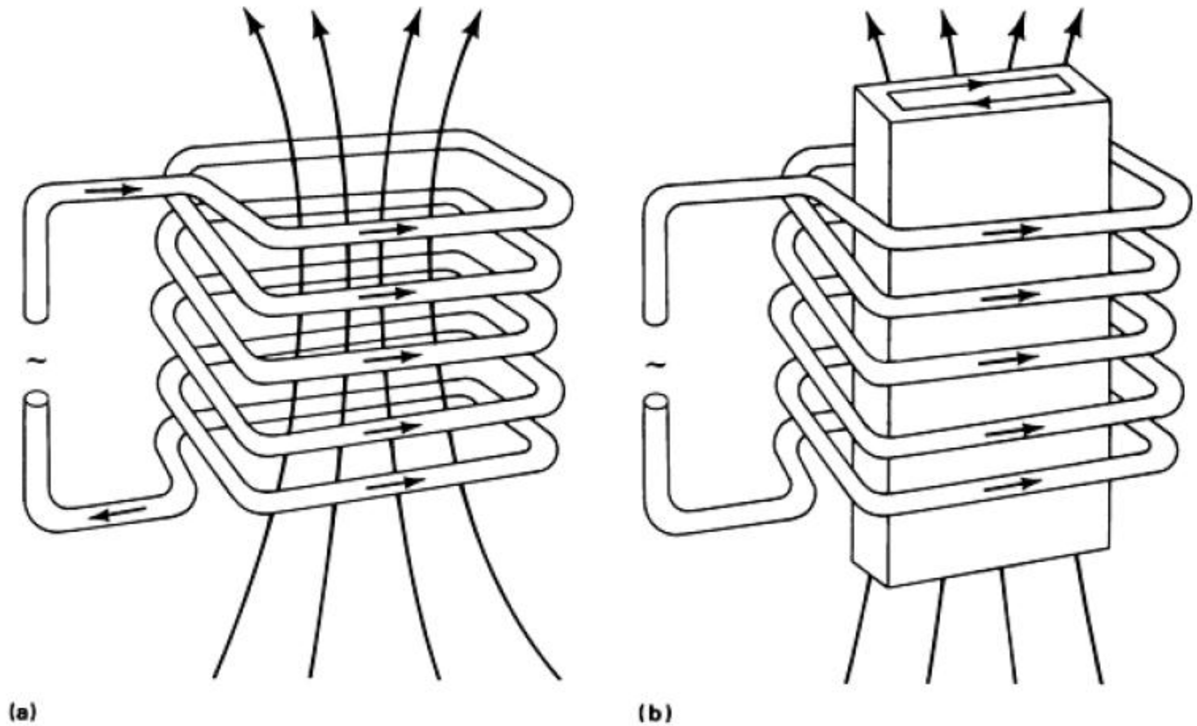


Fig. 1 Pattern of currents and the magnetic field in a solenoid coil (a). In (b), note that the induced eddy current in the specimen is opposite to that in the coil.

Induction Hardening (Frequency effect)

	Figure 3(a) presents plots of • Penetration depth at various frequencies as a function of electrical resistivity. • Illustrates different frequency requirements for a given penetration depth during various steel processing methods. These variations occur for any given material, because the resistivity of conductors varies with temperature. Furthermore, for ferromagnetic metals, the relative permeability varies with temperature, decreasing to a low value at the so-called Curie temperature.

Induction Hardening (Frequency effect)

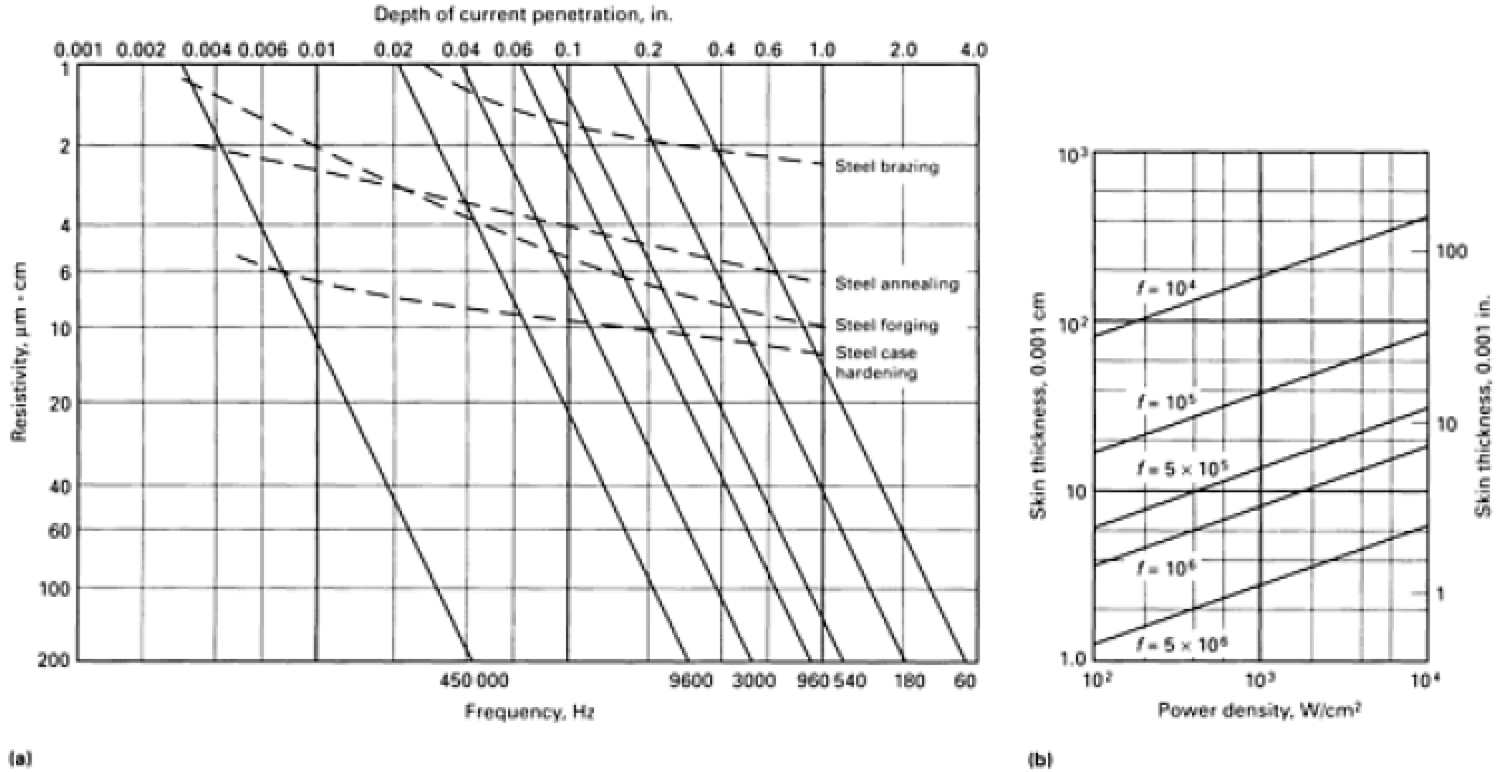


Fig. 3 Plots of penetration depth at various frequencies as a function of electrical resistivity. (a) Curves of current penetration versus frequency for induction heating with longitudinal flux. The dashed lines represent the reference depth for ferromagnetic steel below the Curie temperature for various operations. (b) Reference (skin) depth for magnetic steel as a function of power density

Induction Hardening (Frequency effect)

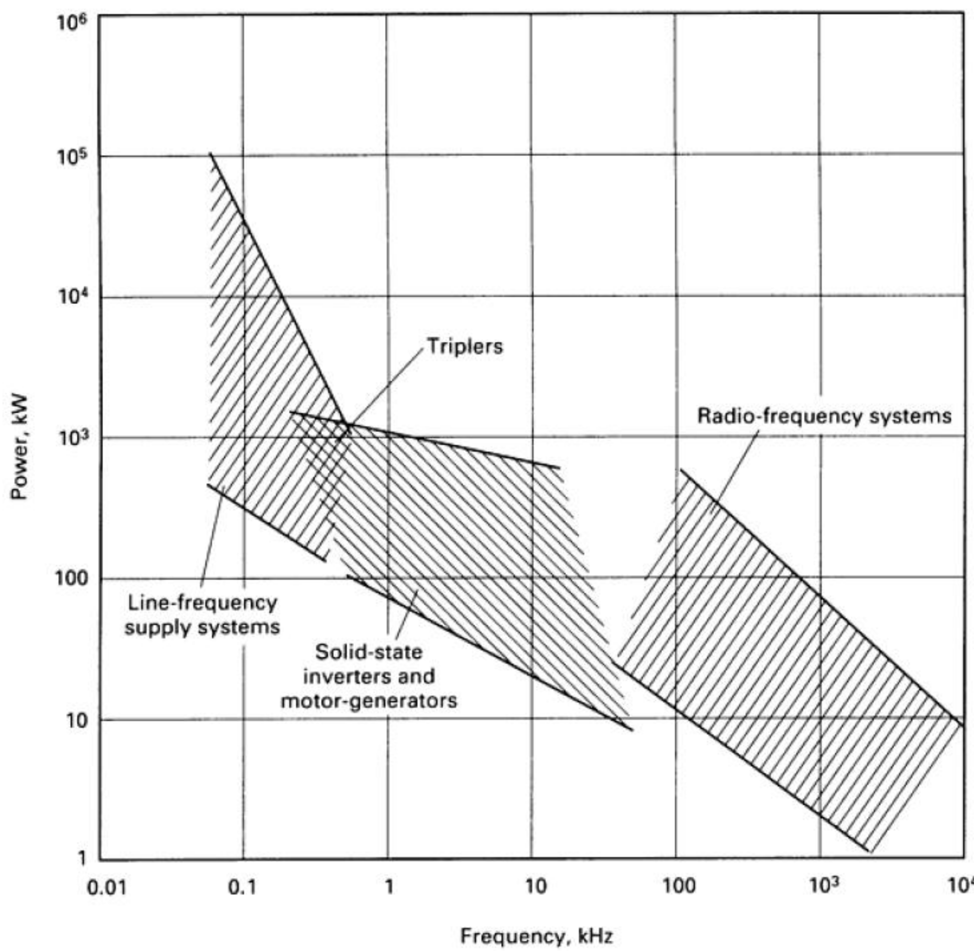


Fig. 5 Ranges of power ratings and frequencies for various induction power systems

Induction Heating Generator

Table 2 Characteristics of the four major power sources for induction heating

Power source	Frequency range	Power range	Efficiency %	Features
Line frequency	60 Hz	100 kW to 100 MW	90-95	High efficiency; low cost; no complex equipment; deep current penetration
Motor-generator	500 Hz to 10 kHz	10 kW to 1 MW	75-85	Low sensitivity to ambient heat; low sensitivity to line surges; fixed frequency; low maintenance cost; spares not needed
Solid state	180 Hz to 50 kHz	1 kW to 2 MW	75-95	No standby current; high efficiency; no moving parts; needs protection outdoors; no warmup time; impedance matches changing loads
Vacuum tube	50 kHz to 10 MHz	1 kW to 500 kW	50-75	Shallow heating depth; localized heating; highest cost; impedance matches changing loads; lowest efficiency

Coils for Induction Heating

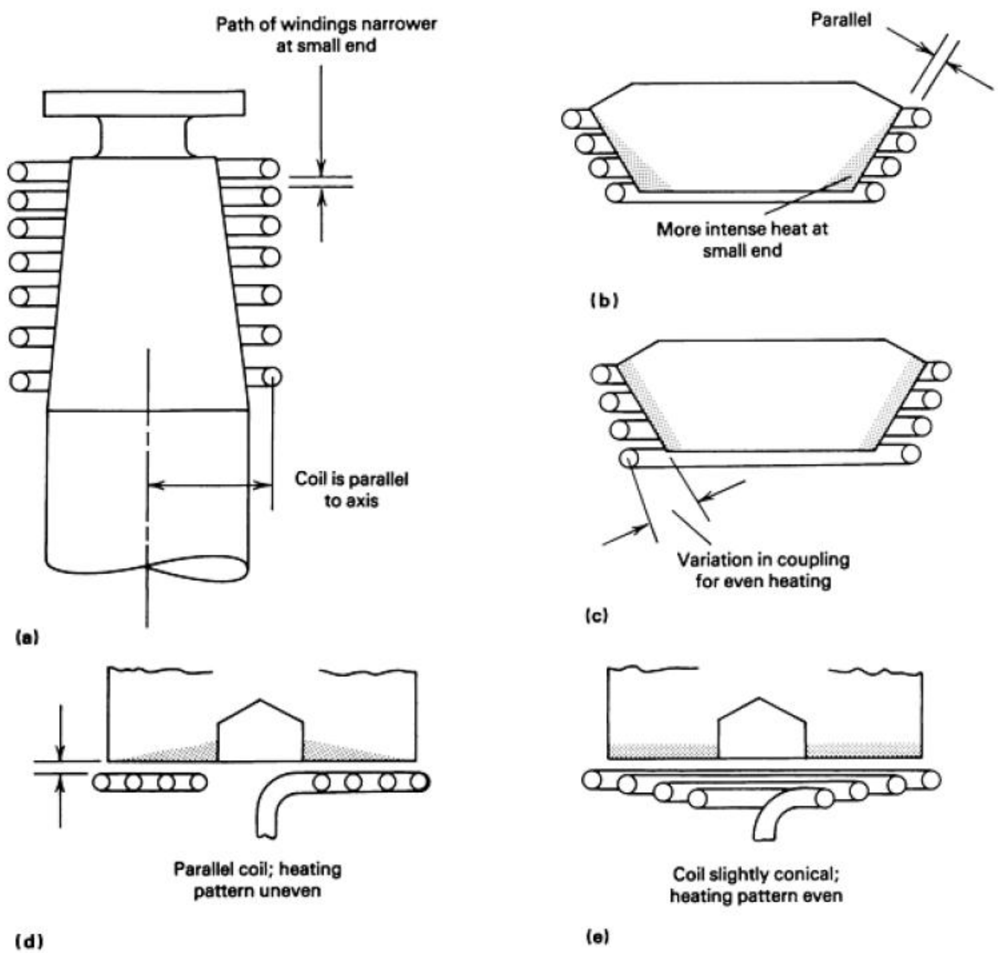


Fig. 16 Adjustment (coil characterization) of induction heating patterns for several parts by varying the coupling distance or turn spacing

Coil Designs

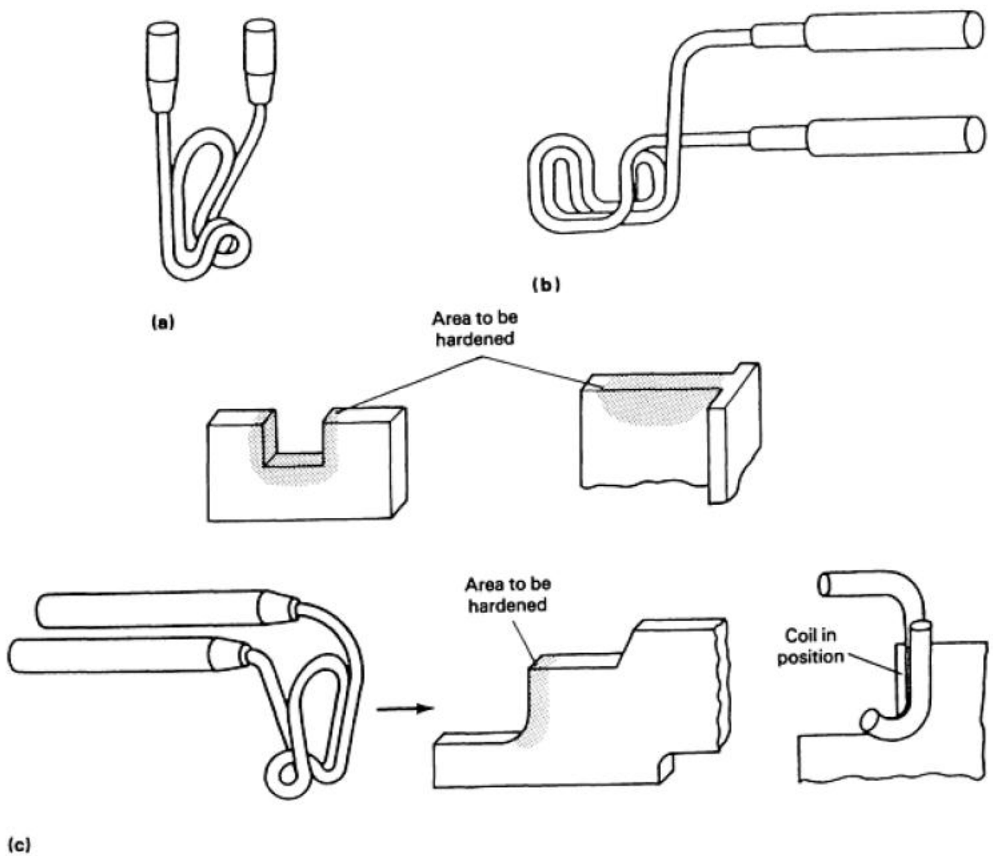


Fig. 15 Coil modifications for localized heating of three different parts

Induction Heating (Heating Patterns)

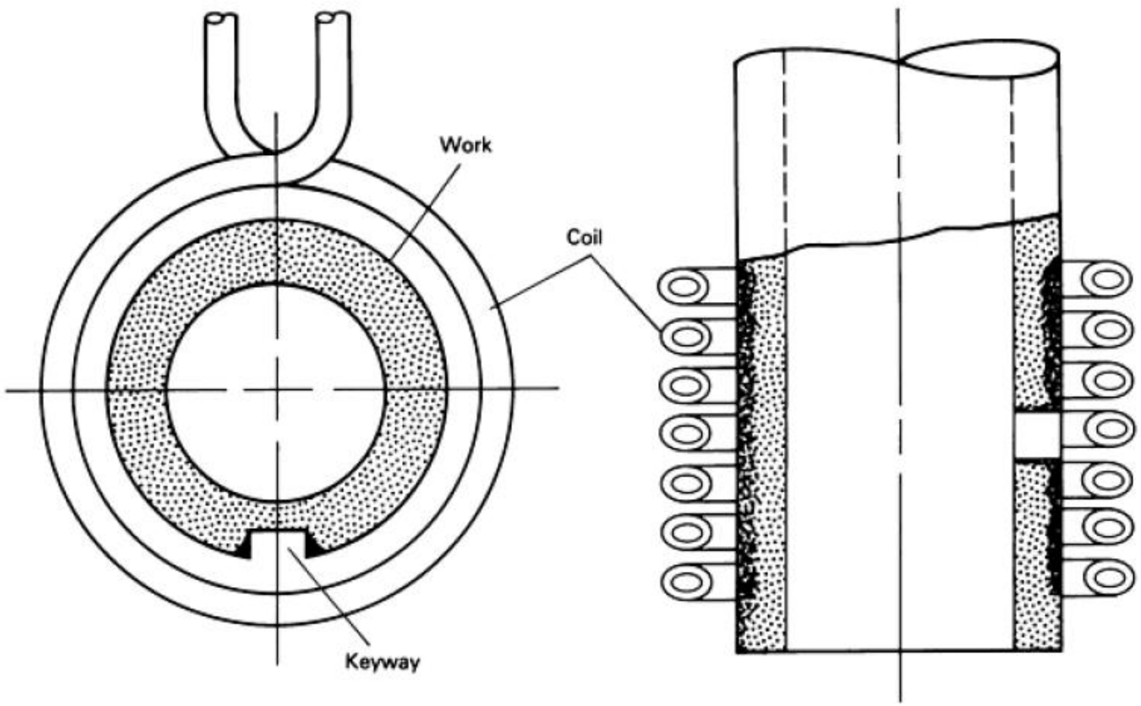
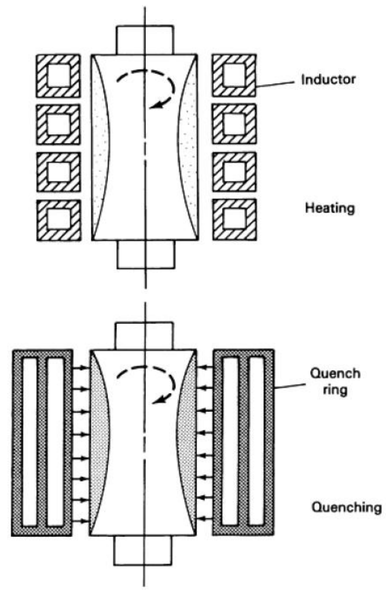
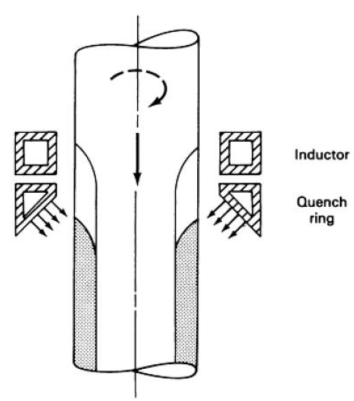


Fig. 19 Localized overheating of sharp corners, keyways, and holes most prevalent in high-frequency induction heating

Induction Hardening Quench Styles



(a)



(b)

Effect of Core Structure

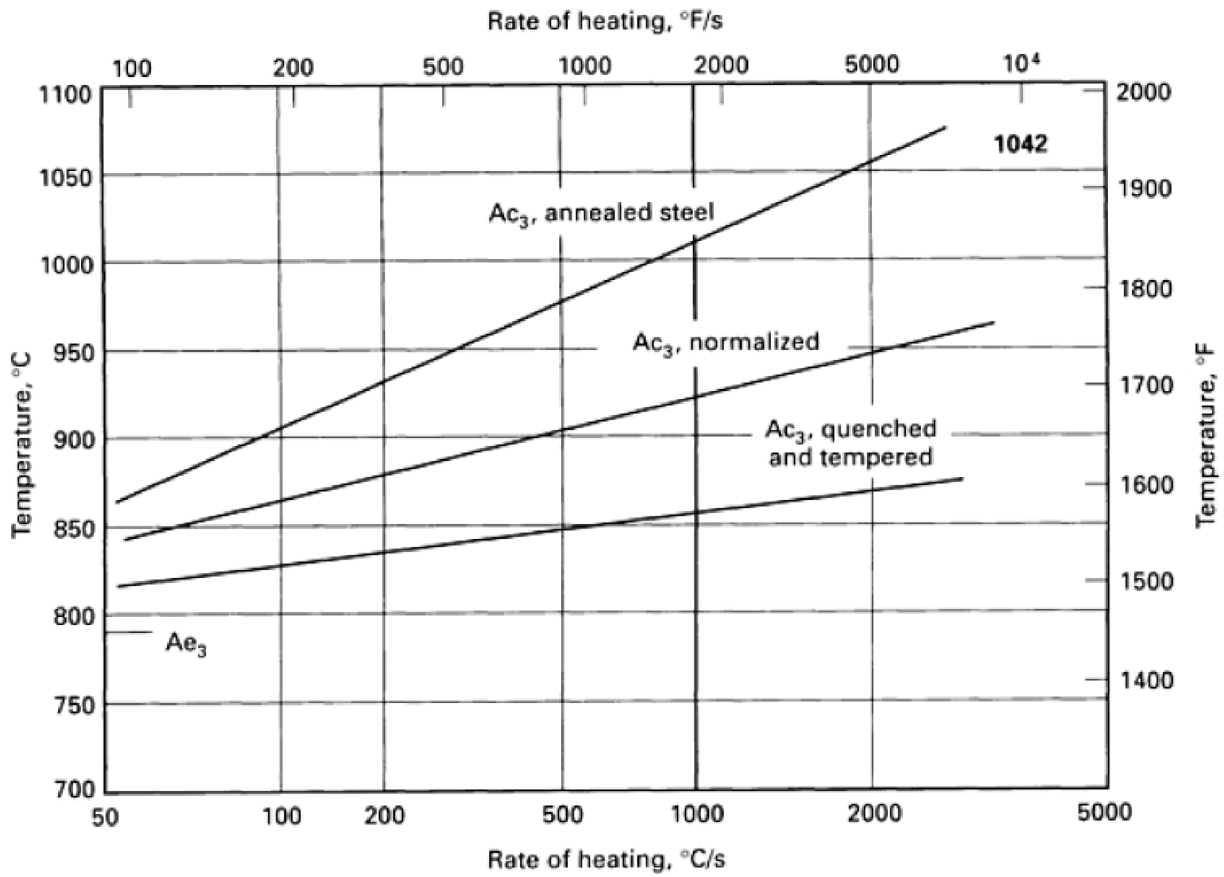


Fig. 33 Effect of prior structure and rate of heating on Ac_3 transformation temperature of 1042 steel

Heating time and Power density

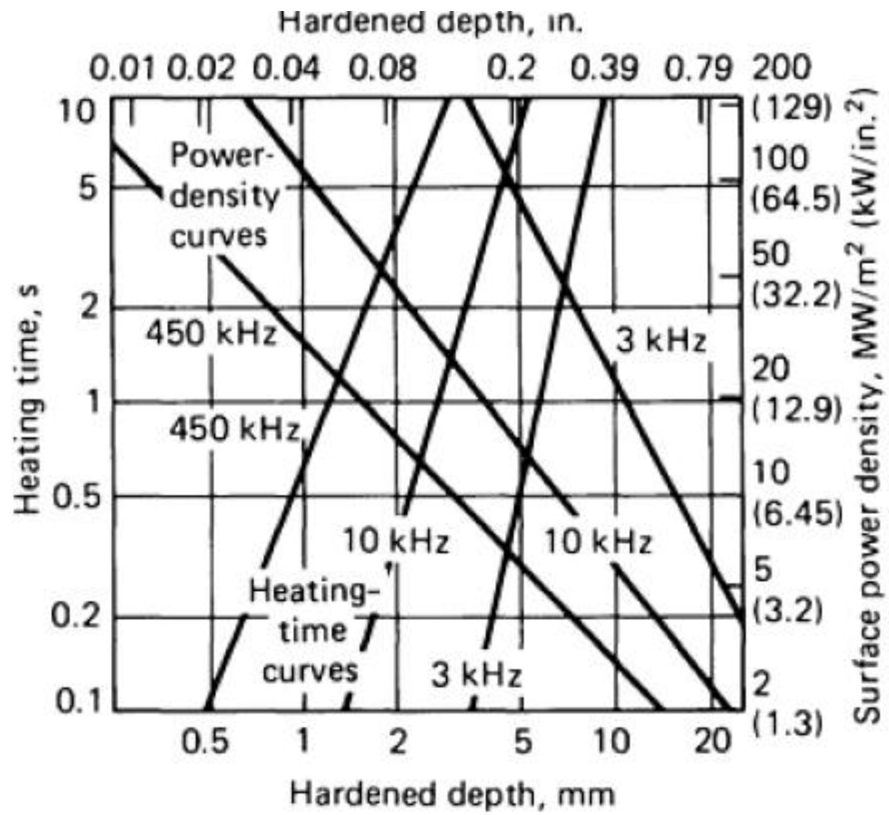


Fig. 39 Interrelationship among heating time, surface power density, and hardened depth for various induction generator frequencies

Effect of Induction Hardening on Fatigue strength

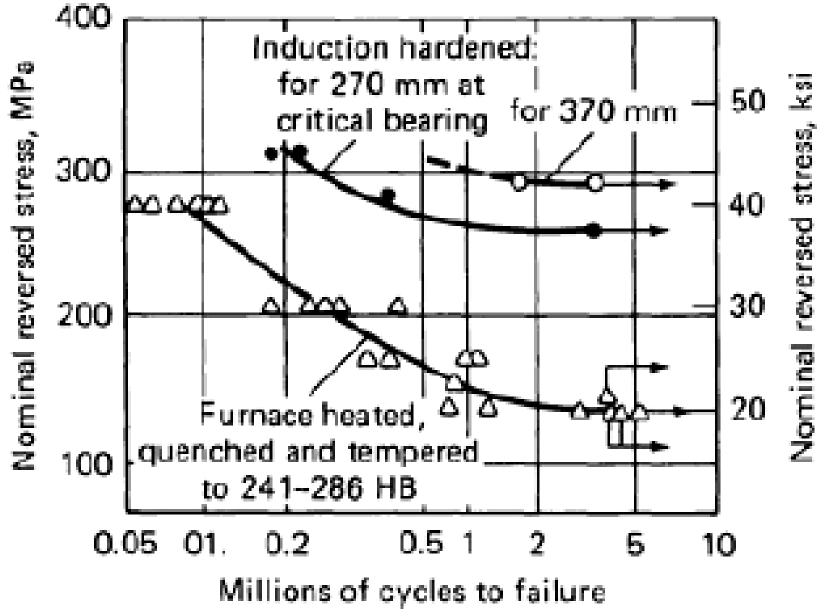
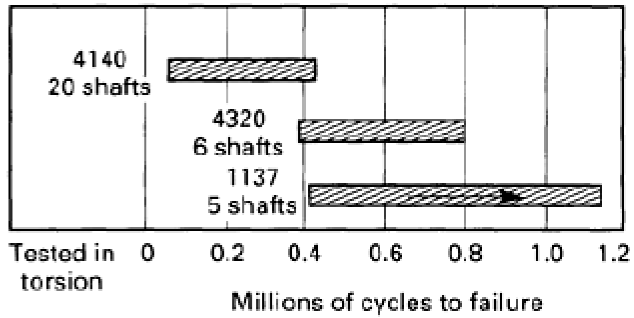


Fig. 45 Bending fatigue response of furnace hardened and induction hardened medium-carbon steel tractor axles. Shaft diameter: 70 mm (2.75 in.). Fillet radius: 1.6 mm (0.063 in.)

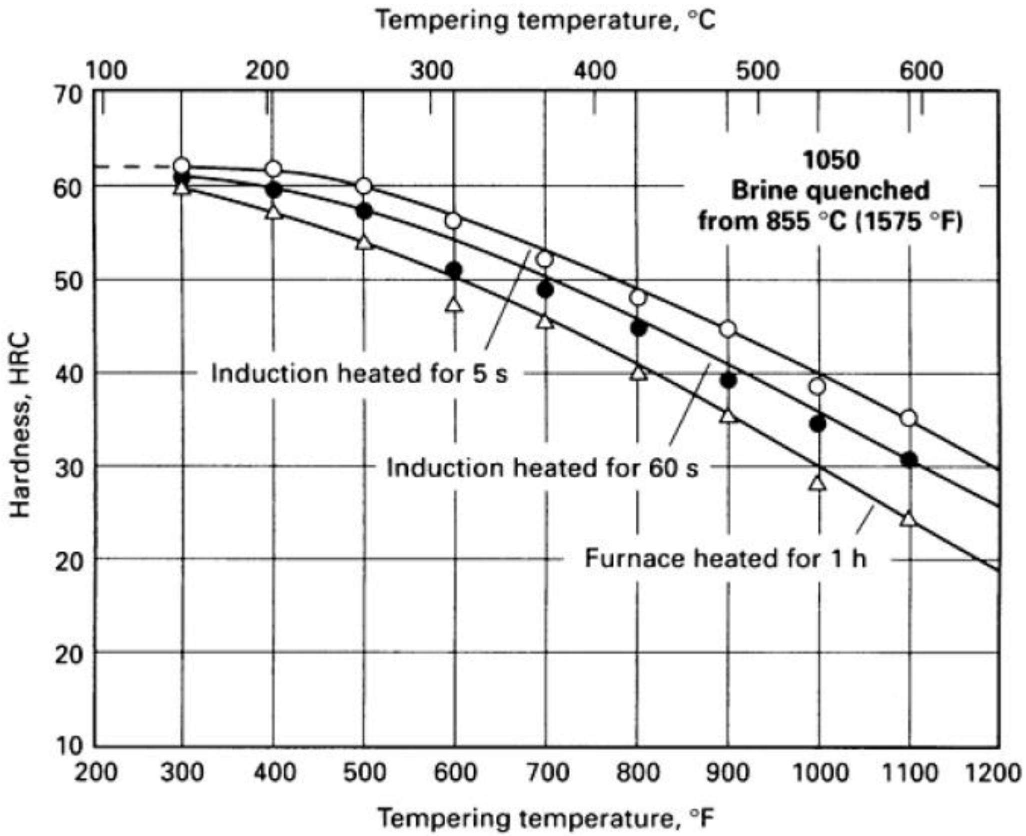
Effect of Induction Hardening on Fatigue strength



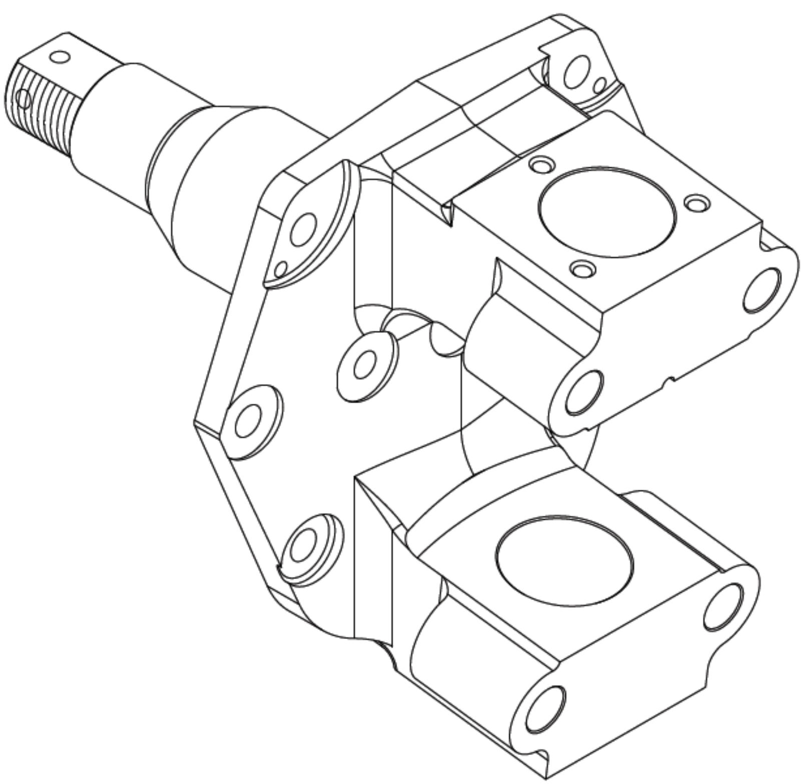
Steel	Surface hardness, HRC	Method of hardening
4140	36-42	Through-hardened
4320	40-46	Carburized to 1.0-1.3 mm (0.040-0.050 in.)
1137	42-48	Induction hardened 3.0 mm (0.120 in.) min effective depth and 40 HRC

Fig. 46 Comparison of fatigue life of induction surface hardened transmission shafts with that of through-hardened and carburized shafts. Arrow in lower bar (induction hardened shafts) indicates that one shaft had not failed after testing for the maximum number of cycles shown.

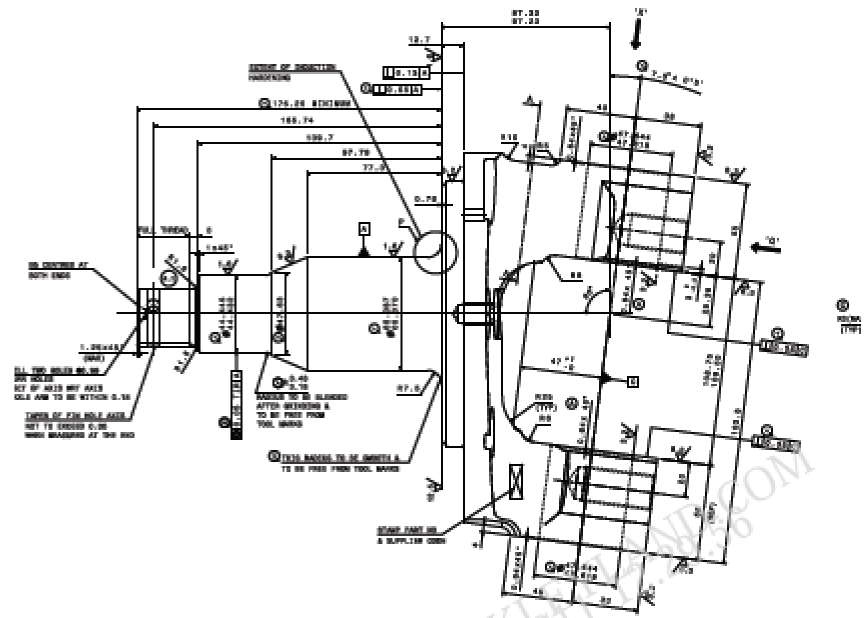
Induction Tempering

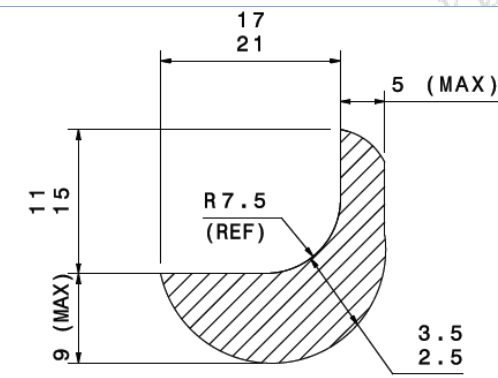


Stub Axle



ISOMETRIC VIEW





RADIUS TO BE FREE FROM
TOOL MARKS

INDUCTION HARDEN FILLET RADIUS
DEPTH OF HARDENED ZONE 2.5/3.5
TEMPER AT 180°C MINIMUM
SURFACE HARDNESS: 540 HV5 MINIMUM } (S)

DETAILS OF CASE DEPTH AT 'P'

PART NO	F3218511	(A) F3217911	(A) F0E02011
(A) MATERIAL SPEC.	STEEL 30Mn5	STEEL 42Cr V6	40Cr4 TYPE B
(S) CHEMICAL COMPOSITION	C : 0.35 - 0.40 Mn : 1.5 - 1.8 Si : 0.35 - 0.50 Cr : 0.3 - 0.5 V : 0.013 MAX Mo : 0.10 MAX S : 0.03 - 0.045 P : 0.03 MAX Cu : 0.25 MAX Ni : 0.25 MAX	C : 0.38 - 0.46 Mn : 0.50 - 0.80 Si : 0.15 - 0.35 Cr : 1.40 - 1.70 V : 0.07 - 0.12 S : 0.015 - 0.04 P : 0.035 MAX	C : 0.35 - 0.45 Mn : 0.60 - 0.90 Si : 0.10 - 0.35 Cr : 0.90 - 1.20 S : 0.035 MAX P : 0.035 MAX
HEAT TREATMENT	HARDENED & TEMPERED (POLYMER QUENCHING)	HARDENED & TEMPERED	HARDENED & TEMPERED
HARDNESS	248 - 302 BHN (#.1)	248 - 302 BHN	248 - 302 BHN
(S) MECHANICAL PROPERTIES	TENSILE STRENGTH : 79 KG/MM SQ.MIN (#.1) YIELD STRENGTH : 60 KG/MM SQ.MIN % OF ELONGATION : (GL = 5D) 12 MIN IZOD : 28 FT - LB MIN	AS PER ALS 258.14	TENSILE STRENGTH : 79 KG/MM SQ.MIN YIELD STRENGTH : 60 KG/MM SQ.MIN % OF ELONGATION : (GL = 5D) 12 MIN IZOD : 28 FT - LB MIN
(B) SURFACE PROTECTION	SURFACE PROTECTION TO MEET:ALS:268.03; SSR LIFE:300 HRS. MACHINED SURFACES TO BE PROTECTED WITH RUST PREVENTIVE OIL TO IS-1154.		

(S) CRACK DETECT AFTER FINAL GRINDING
AT FILLET RADIUS ZONE

Ferritic Nitrocarburizing

Purpose	Ensure : Hard wear and fatigue resistant case Soft core
Components	• Crankshaft • Thin and slender components • Valve tappets
Common steels	medium carbon (0.3% to 0.5%) Carbon steel Alloy additions depend on the core properties required
Process	Core: desirable core structure to meet strength requirements can be achieved by either normalizing or by hardening and tempering Case : Case depth and hardening is achieved by induction heating and followed by quenching of the surface only.
Properties achieved	Case Hardness :approx. 650 VPN 0,5 Case Depth : 0.3 mm (typical)

Ferritic Nitrocarburizing (Typical)

	Temperature˚C	Time Hrs	Details
Degreasing	80-100	0.25	
Harden	OQ from AC3 810-840	1 to 2	
Degrease	80-100	0.25	
Temper	550- 600	2 hrs	
Clean if required			
Nitrocarburizing	570	2 to 6	Carburizing + ammonia atmosphere. Water/ polymer quench

Ferritic Nitrocarburizing

	FERRITIC NITROCARBURIZING processes are those thermochemical treatments which involve the diffusional addition of both nitrogen and carbon to the surface of ferrous materials at temperatures completely within the ferrite phase The primary object of such treatments is usually to improve the anti-scuffing characteristics of ferrous engineering components by producing a "compound layer" on the surface which has good tribological properties (Fig. 1). In addition, the fatigue characteristics of the material can be considerably improved, particularly when nitrogen is retained in solid solution in the "diffusion zone" beneath the compound layer. This is normally achieved by quenching into oil or water from the treatment temperature, usually 570 °C (1060 °F).

Ferritic Nitrocarburizing

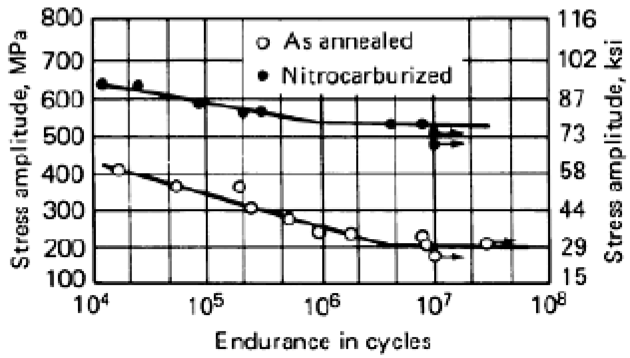


Fig. 8 Wohler fatigue curves for unnotched specimens of untreated and gaseous nitrocarburized mild steel. Source: Ref 2

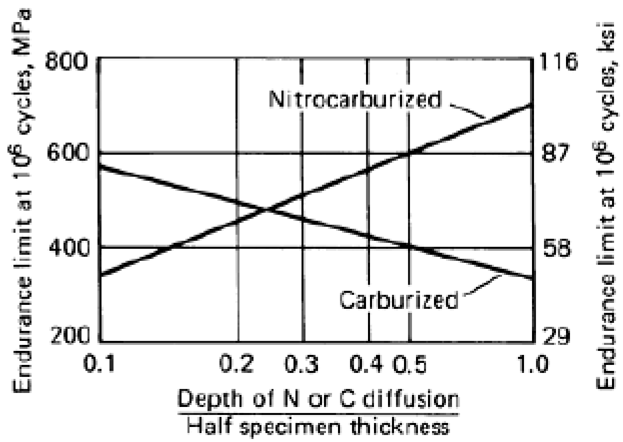


Fig. 9 Fatigue strength of low-carbon steel nitrocarburized at 570 °C (1060 °F) or carburized at 900 °C (1650 °F). Source: Ref 20

RESIDUAL STRESSES AND THEIR EFFECTS ON FATIGUE RESISTANCE

•To improve fatigue resistance we should try to avoid tensile mean stress and have compressive mean stress. This can often be achieved by using residual stresses.

•Residual stresses are in **equilibrium** within a part, without any external load.

•They are called residual stresses because they remain from a previous operation.

•Residual stresses exist in most manufactured parts and their potential to improve or ruin components subjected to millions of load cycles can hardly be overestimated.

S-N behavior of a Ni-Cr alloy steel subjected to rotating bending with three different surface conditions involving

- ■smooth (solid circles),
- ■notched (x's), and
- ■notched shot-peened (open squares) specimens.

With the notched shot-peened specimens, the fatigue resistance is essentially the same as the smooth specimens. Thus, the notch became perfectly harmless after it was shot-peened due to the desirable residual compressive stresses.

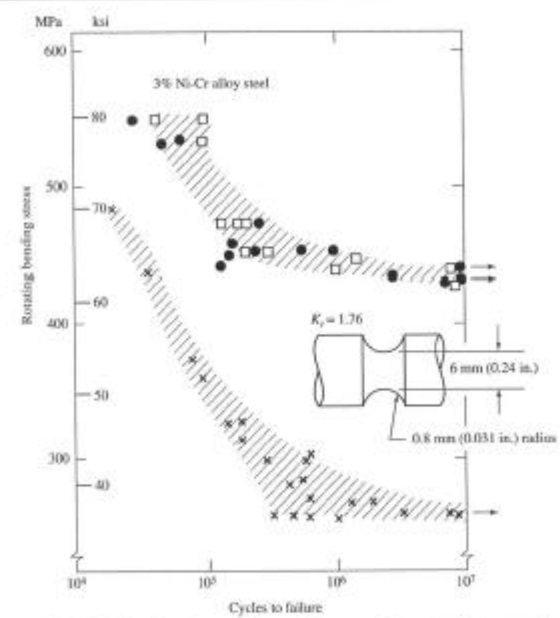


Figure 8.1 S–N behavior for smooth, notched unpeened, and notched peened sp imens [1] (reprinted with permission of Pergamon Press). (●) smooth, polist (x) notched, (□) notched, shot-peened.

PRODUCTION OF RESIDUAL STRESSES & FATIGUE RESISTANCE

The many **methods**of inducing residual stresses in parts can be divided into four main groups:

Mechanical Methods

Thermal Methods

Plating

Machining

MECHANICAL METHODS

Mechanical methods of inducing residual stresses:

Rely on applying external loads that produce localized inelastic deformation.

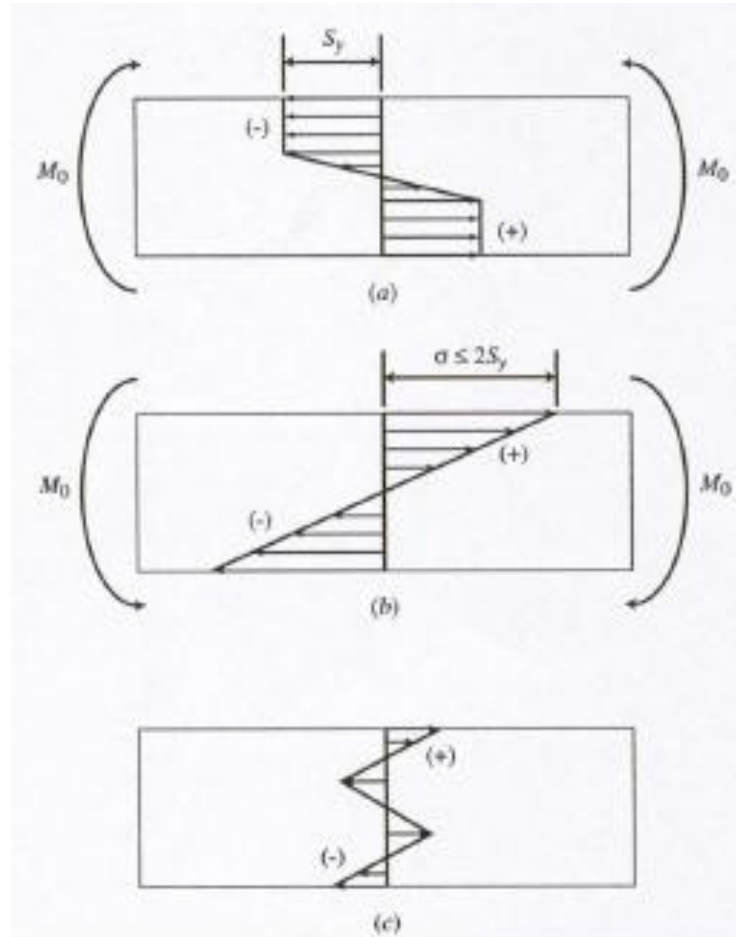
Upon removing the external loading, elastic “springback” occurs that produces both tensile and compressive residual stresses.

Both tensile and compressive residual stresses must be present in order to satisfy all equations of internal force & moment equilibrium, F =M =0.

MECHANICAL METHODS

Figure 8.2 shows this process for inelastic bending of a beam behaving in an elastic-perfectly plastic manner.

- The beam in Fig. 8.2c will have better fatigue resistance at the bottom fibers than at the top fibers.
- Thus, straightening of parts by bending is usually detrimental due to the undesirable tensile residual stresses that form in regions overloaded in compression.
- If the material were not elastic-perfectly plastic, the residual stress distribution in Fig. 8.2c would be non-linear.



MECHANICAL METHODS

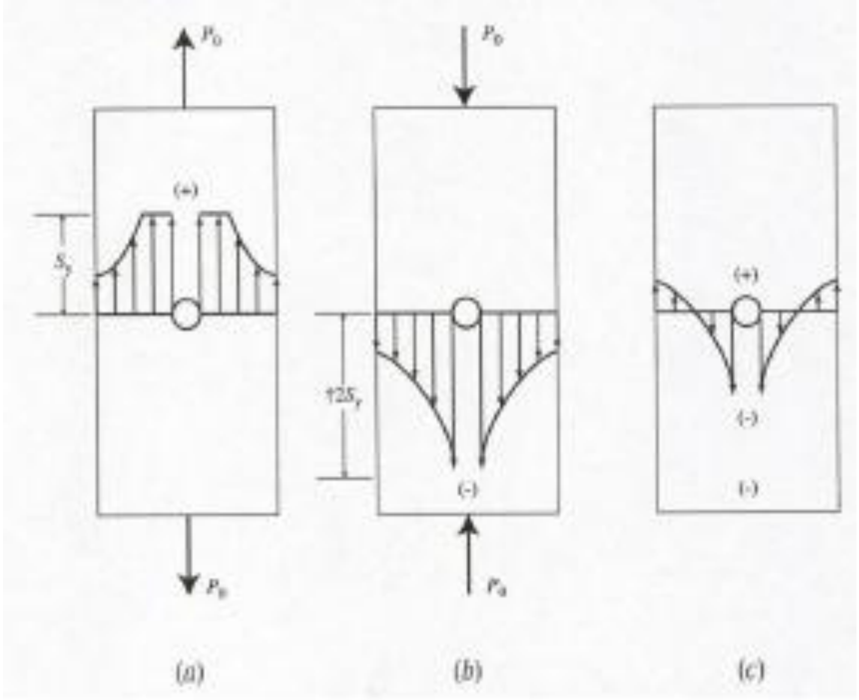
Stretching(tensile overload) of the notched specimen shown.

■Again, the material is assumed to be elastic-perfectly plastic.

■Nonuniform tensile stress distribution during the inelastic loading.

■The summation of the inelastic loading stresses and the elastic unloading stresses result in the residual stress distribution shown in Fig. 8.3c.

■Note that tensile overloads with notches result in desirable residual compressive stresses at the notch, while compressive overloads with notches result in undesirable residual tensile stresses at the notch



MECHANICAL METHODS

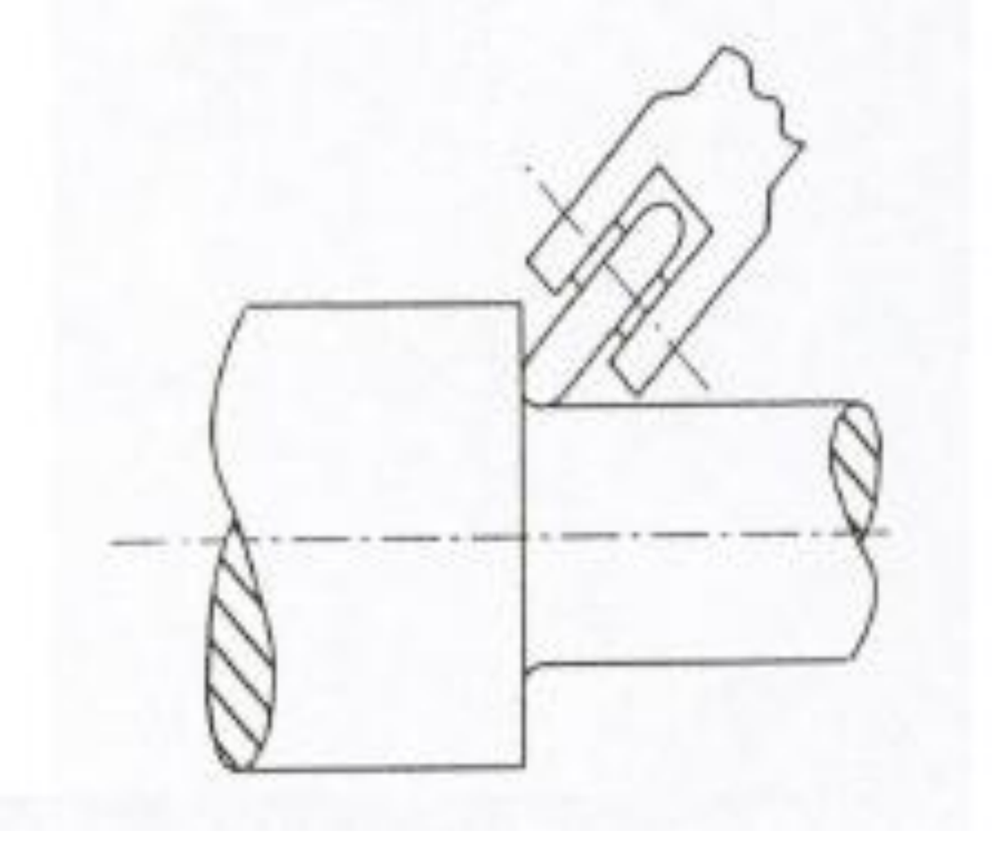
The most widely used mechanical processes for producing beneficial compressive surface residual stresses for enhancing long and intermediate fatigue life are: (1)**shot-peening**and (2)**surface rolling**.

■Both methods use local plastic deformation, one by the pressure of the impact of small balls, the other by the pressure of narrow rolls.

■Surface rolling is widely used in the production of threads. It is very economical as a forming operation for bolts and screws, as well as beneficial for fatigue resistance.

MECHANICAL METHODS

Rollingis also used for producing desired compressive residual stresses in fillets for components such as crankshafts, axles, gear teeth, turbine blades, and between the shank and head of bolts.



MECHANICAL METHODS

Shot-peening has been used successfully with steels, ductile iron and aluminum, titanium, and nickel base alloys.

 Small balls (shot) that range from 0.18 to 3.35 mm with different size specifications are thrown or shot at high velocities against the work piece.

They produce surface dimples and would produce considerable plastic stretching of the skin of the part if this were not restrained by the elastic core.

MECHANICAL METHODS

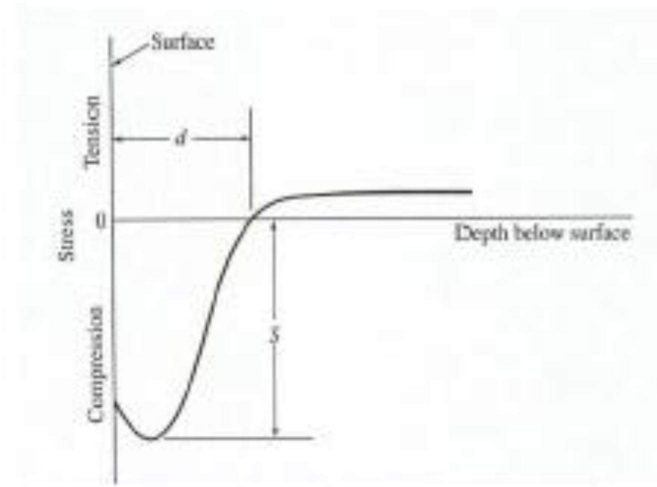
- Compressive stresses are thus produced in the skin. The depth of the compressive layer and the dimpled surface roughness are determined by
- ■the material of the work piece
- ■the intensity of peening, which depends on
  - ■size of shot,
  - ■Material of shot,
  - ■velocity or flow rate of the shot,
  - ■time of exposure.
- ■The magnitude of the compressive residual stress depends mainly on the material of the work piece.

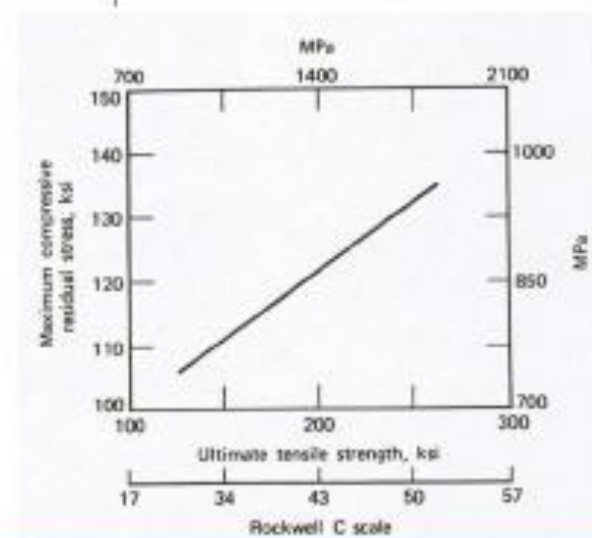
MECHANICAL METHODS

Typical stress distribution produced by **shot-peening**.

■The depth of the residual compressive stress, distance d, ranges from about 0.025 to 0.5 mm (0.002 to 0.02 in).

■The relation of the stress peak to material hardness is shown in Fig. 8.6





MECHANICAL METHODS

Shot-peening is used on many parts:

- From small blades for chain saws to large crankshafts for diesel locomotives.
- Application to high performance gears and to springs is almost universal.
- Figure 8.7, for carburized gears, shows a tenfold fatigue life increase.

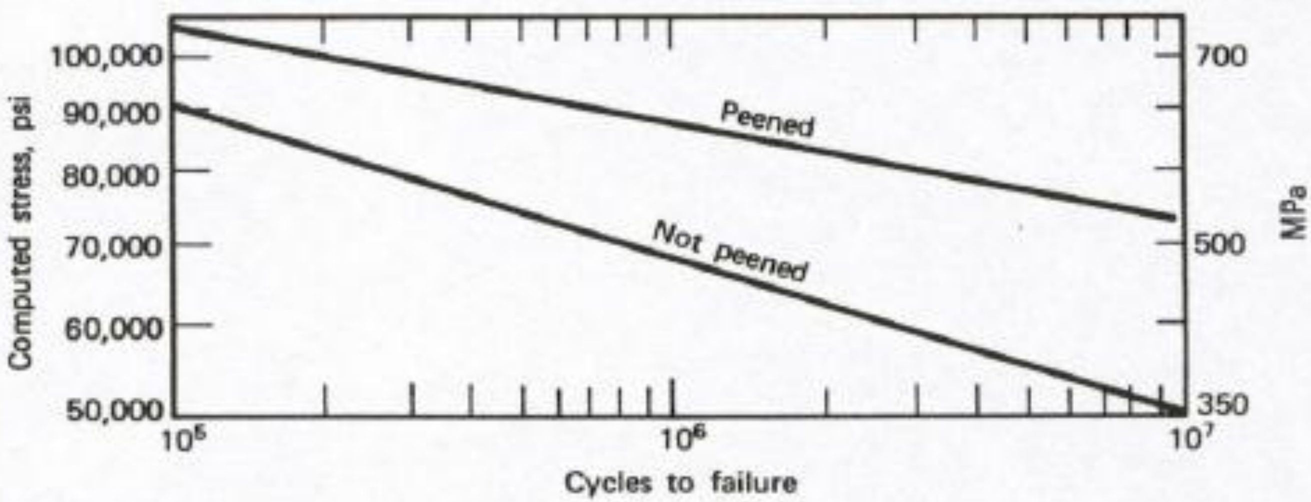


Figure 8.7 Effect of shot-peening on fatigue behavior of carburized gears [13] (reprinted with permission of McGraw-Hill Book Co.).

MECHANICAL METHODS

Adequate depth of the compressively stressed layer is important.

- The compressed layer must be deep enough to be able to stop cracks.
- Due to the compressive layer, fatigue crack nucleation sites and growth may sometimes be shifted to subsurface residual tensile stress regions.

Other mechanical processes that achieve improvement of fatigue strength by compressive residual stresses include

- coining around holes,
- expansion of holes,
- hammer-peening of welds.

MECHANICAL METHODS

- Residual stresses are especially valuable when used with harder materials because the full potential of greater yield strength can be used only if the damaging effect of notches can be overcome.

- Fig. 8.8 shows that shot-peening increased the fatigue limit by a factor of 1.25 to 1.5 for $S_u \approx$ 1000 MPa (145 ksi), and 2 to 2.5 for $S_u \approx$ 1800 MPa (260 ksi).
  a) shaft not peened
  b) shaft peened
  c) scratched plate not peened
  d) scratched plate peened