SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

SAE ARP4715

Issued 2000-12
Reaffirmed 2011-04

Induction Hardening of Steel Components

RATIONALE

This document has been reaffirmed to comply with the SAE 5-year Review policy.

1. SCOPE:

This recommended practice provides guidelines for the establishment of an induction hardening process for steel components. It is intended to be used as a guide for designers of induction hardened parts, for process auditors, and for purchase specifications and/or process sheets as applicable.

Induction heat treatment is intended for hardening of only selected areas of plain carbon or alloy steel components. A prior heat treatment may be specified for improved response of the overall component to induction hardening, or for control of properties in the balance of the part. AMS 2759 is recommended for such prior heat treatment.

2. APPLICABLE DOCUMENTS:

The following documents are often used in conjunction with induction hardening and should be considered when induction hardening is needed:

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AMS 2759 Heat Treatment of Steel Parts, General Requirements
AMS 2649 Etch Inspection of High Strength Steel Parts

SAE J423 Methods of Measuring Case Depth

ARP1820 Chord Method of Evaluating Surface Microstructural Characteristics

2.2 ASTM Documents:

Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19248-2959.

ASTM E 18 Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials
ASTM E 92 Vickers Hardness of Metallic Materials
ASTM E 112 Determining the Average Grain Size
ASTM E 384 Microhardness of Materials

3. TECHNICAL:

3.1 Specifying Induction Hardening:

The extent of the induction hardening pattern should be fully defined on the engineering drawing. The definition should include:

The minimum and maximum lengths or widths of the hardened zone or case (sometimes called induction harden pattern or IHP)
The minimum and maximum depth of the hardened zone or case
The minimum (and in some cases, the maximum) hardness of the case
The hardness of the core or unaffected base metal
The maximum extent of the heat affected, transition, or intermediate zones. These terms are often used interchangeably.
The minimum hardness permitted in the overtempered zone (In some cases, the width of the intermediate or transition zone may also be limited.)
Locations where hardness measurements or traverses should be taken.

Examples of ways to specify the extent and requirements of induction hardening are shown in Figure 1.

3.1.1 The transition or overtempered zone is located beneath the hardened zone. Having been exposed to temperatures not high enough to harden it, but substantially higher than the core or base metal tempering temperature, this area may be softer than the core or base metal. The designer may limit the extent of softening, either by specifying a minimum hardness, or by specifying the maximum width of the zone, or both. It is recommended that the permissible hardness reduction in the overtempered or transition zone be 4 to 8 points HRC below the original core or base metal hardness. A minimum width of 0.03 inch (0.76 mm) is often obtainable for smaller sections, but specifying the maximum width that can be tolerated in the design is recommended. A transition zone equal to the minimum case depth required by the specification or drawing is considered reasonable.

3.1.2 Hardness at the surface of the induction hardened range is generally measured by direct Rockwell or Superficial Rockwell hardness testing in accordance with ASTM E 18. However, depth of hardening and extent of heat affected zone are normally determined destructively, on a cross-section of the part, using microhardness techniques such as those of ASTM E 384, ARP1820 or SAE J423.

3.1.3 Material:

3.1.3.1 Type of Steel: In general, steels with carbon contents of 0.35% or more will respond to induction hardening, although a carbon content approaching 0.5% may be necessary to obtain hardnesses exceeding 55 HRC. A fine grained steel (ASTM No. 5 to 8 determined in accordance with ASTM E 112) is desirable. In general, low alloy steels that have been normalized and tempered or quenched and tempered in accordance with AMS 2759 are desirable.

3.1.3.2 Tempering After Induction Hardening: The as-induction hardened microstructure is dependent on material composition, hardenability, prior structure and quench rate, and will generally consist of a martensitic structure. Since the martensitic structure is normally crack sensitive after cooling from the hardening temperature, the entire part is invariably tempered after induction hardening, at temperatures ranging from 300 to 1000 °F (149 to 538 °C). The designer may specify a specific tempering temperature or may specify a maximum or minimum case hardness. However, in all instances, the drawing must require tempering after hardening.

3.1.3.3 Microstructure: Unless the designer specifies otherwise, the resultant microstructure should consist of tempered martensite at the surface and throughout the case or induction hardened zone. All areas of the induction hardened case should meet the minimum case hardness, with a relatively sudden drop to below the base metal hardness at the start of the transition zone (See Figure 2). Typically, grain size, when determined, which is often equated with toughness, should not increase by more than one or two ASTM grain size numbers, but in no instance should the designer expect grain sizes larger than ASTM No. 3 when starting with a grain size of ASTM No. 5 to 8, nor evidence of free ferrite at the surface, both indicative of excessive heating and detrimental to performance or reliability.

An insufficient quench may result in a portion of the material remaining untransformed. Standards for such untransformed material, called retained austenite, may be specified by the designer.

3.1.4 Recommended Case Depths: The case depth selected by the designer depends on the application and section size. For surface hardening, the depth should be less than one third of the cross-sectional thickness of the part, and, when calculated, should exceed with reasonable margin the depth of maximum shear stress created by calculating the maximum bearing load or stress.

3.2 Equipment:

Induction heat treating equipment consists of a power supply with appropriate controls, an inductor or coil that transmits the power from the supply to the work, means of matching the power supply to the inductor or coil, and, if necessary, means for quenching the heated sections or complete components as required.

3.2.1 Inductor or Coil: The inductor is a loop (partial loop or several loops) of current carrying conductor similar to the primary circuit of a transformer, that transmits power from the power supply to the work. The heating current is electrically induced into the work as the secondary of the transformer, forming eddy currents that produce I^2R heating, and is not part of the power circuit directly. The inductor, or coil, may be as simple as a single turn of water cooled copper tubing, or may contain iron laminations or iron powder to help direct the magnetic field.

Each inductor or coil should be assigned a part or tool number. Since the pattern produced is a function of the shape of the coil, each part or component should have a specific inductor or coil assigned to it.

The coupling between the component and the inductor is one of the determining factors in the efficiency of the coil. Generally, the closer the work is to the inductor, the greater the power transmitted, and the more accurate the pattern. Typical gaps between inductor and component range from 0.02 to 0.1 inch (0.5 to 2.5 mm).

3.2.2 Power Supplies: Power supplies as described in Table 1 are generally acceptable for use.

TABLE 1 - Typical Power Supplies

Type	Frequency (KHz)	Typical Power Rating (KW)
Vacuum Tube Oscillator	200 to 450	5 to 600
Motor Generators	1, 3, 10	7.5 to 500
Frequency Inverters	0.5, 1, 3, 10	50 to 1500
Frequency Multipliers	180, 540	100 to 1000

3.2.2.1 To control the power supply for induction hardening, there should be a means to turn it on and off, select the power level, and control and regulate the power. Since heating is usually accomplished in seconds and fractions of seconds, it is recommended that the controls be provided with a series of on-off push buttons to start timers that automatically control on-time, potentiometers for measuring watts, volts, amperes, frequency, and reactive power or power factor, as applicable.

3.2.2.2 The depth to which the induced current flows in the workpiece or component is inversely related to the power supply frequency. Table 2 shows a relationship between power supply frequency and depth of direct I^2R heating. The minimum values are for high power densities (typically 15KW / square inch or 15 KW / 6.5 square cm). Note that the minimum depth is approximately the depth of the zone actually heated by the eddy currents induced by the inductor. Additional depth of heating is obtained by increasing the power supply “on-time” to allow the heat to drift or diffuse beyond the directly heated minimum depth. However, the longer the drift, the wider the heat affected or intermediate or transition zone will be. Too deep a zone with too high a frequency may result in overheating at the surface. Conversely, a shallow pattern cannot be obtained with a low frequency power supply. The depths given in Table 2 are not absolute; different materials in different heat treated conditions will produce different results.

TABLE 2 - Frequency / Depth of Hardening Relationship

Frequency cycles per second	Practical Hardening Depth Inch (mm), minimum	Practical Hardening Depth Inch (mm) working
500	0.2 (5)	0.4 to 0.6 (10 to 15)
1,000	0.1 (2.5)	0.18 to 0.35 (4.5 to 9)
3,000	0.06 (1.5)	0.15 to 0.2 (3.7 to 5)
10,000	0.04 (1)	0.1 to 0.15 (2.5 to 3.7)
120,000	0.3 (0.75)	0.06 to 0.1 (1.5 to 2.5)
500,000	0.02 (0.5)	0.04 to 0.08 (1 to 2)
1,000,000	0.01 (0.25)	0.01 to 0.04 (0.25 to 1)

3.2.2.3 The inductor or coil should be well matched to the workpiece and power supply. Ideally, load matching or impedance matching should be within 15% of the full rated power at or near the 100% voltage and frequency rating. Power supplies should be equipped to regulate power factor for maximum efficiency by adjusting the internal inductance or capacitance as required. Power supplies should be equipped with meters to assist in regulating reactive power or power factor as needed.

3.2.3 Fixturing: The part being treated should be held rigidly and in a reproducibly fixed position to ensure repeatable coil positioning, air gap, and heating pattern. For uniformity of heating pattern, it is often desirable for round components such as shafts, bearing races and similar parts, to be rotated during the heating. Component design and processing capabilities will dictate whether such measures are required.

3.2.4 Quenching: The quench method and media, when required, are determined by the part design and material selection. Some AISI 400 series steels, some highly alloyed tool steels, and steels generally regarded as air hardening, may need no supplementary quenching. However, when supplementary quenchants are required, as in the case of low alloyed or carbon steels, the procedure should specify and control all aspects of the quench, including, as applicable, quenchant agitation, quench delay, quench composition, quench head position, and fluid pressure, spray on-time, and quench immersion time.

3.3 Procedures:

3.3.1 Documentation: Induction heat treatment should be performed in accordance with an established, documented, and reproducible procedure. That procedure should include:

Part number and part name as applicable
Coil or inductor part number
Holding fixture part number
Date procedure was established or last revised
Power supply machine identification
Sketch of the location of the part to be induction hardened
Intensifiers or heat sinks, if used
Power ramping schedule, if used
Power settings
Power cycle time
Coil to workpiece distance and method for assuring it
Quench type

quench head location
quench delay time, as applicable
quenchant composition
fluid flow rate and pressure
time in quench, or on-time of spray quenchant

Temper cycle (normally in accordance with AMS 2759 but may be done by induction. If done inductively, a similar set of instructions would be needed for the induction tempering cycle.)
Test methods and sampling plans

3.3.2 Induction Heating Cycle: The induction heating cycle is established by heating the selected area of one or more parts using the selected fixtures, coil, and preselected procedures. It may be necessary in some cases to reiterate the parameters several times until the desired results are obtained before production parts are made. Initial cycles may be verified by optical pyrometry, temperature indicating lacquers, or other means. After establishment of the cycle, it is usually acceptable to rely on the reproducibility of the procedure and normal quality control methods.

4. QUALITY CONTROL:

4.1 Destructive Examination:

It is recommended that at least one part be destructively examined by sectioning and metallographic examination, since depth of hardening can only be determined destructively. For critical parts, the purchaser may require that parts be destructively examined from each lot or each tool setup, on a statistical basis, or at periodic intervals based on some number of parts or calendar time.

4.1 (Continued):

Examination should include a microhardness traverse that includes sufficient points to ensure the extent of the hardened, transition or intermediate zones, and heat affected zones. Where the pattern is non-uniform due to geometry or other factors, sufficient metallographic sections should be taken to completely characterize the pattern.

4.2 Routine Non-Destructive Examination:

At least one part per set-up or production lot should be checked for hardness and hardness pattern. Direct hardness testing in accordance with ASTM E 18 in the hardened area is suggested, but care must be exercised in selecting the hardness scale used and location of test to assure that the indentation does not introduce unintended stress concentrations. The presence of temper colors are often sufficient to indicate roughly the extent but not the depth or hardness of the induction heated zone. However, for greater accuracy, parts may be grit blasted or temper etched in accordance with AMS 2649. Note, however, that these procedures only examine the surface of the part, and destructive examination would be required to assure the depth of the hardened zone. For critical parts, the purchaser may require that all parts in each lot be direct Rockwell hardness tested and etched or blasted for extent of case, but the process is relatively reproducible, and sampling would be acceptable. Care should be exercised in selecting hardness test locations, since such testing leaves a small impression in the surface that could be detrimental to service of the part.

PREPARED UNDER JURISDICTION OF AMS COMMITTEE “E” AND AMEC