



## Induction Hardening and Tempering of Gray Iron Cylinder Bores

### 1 Scope

This standard covers the requirements for induction hardening and tempering heat treatment of the cylinder bores of gray iron Duramax cylinder blocks. This standard only covers the metallurgical (microstructure and hardness) requirements of the Duramax block and the methods to verify.

**1.1 Material Description.** Induction hardening of the cylinder bores in the DMax cylinder block is performed to improve the wear-resistance in the piston-ring upper ring reversal zone by selectively hardening only the region necessary to accomplish improved wear resistance, see Figure 1. The choice of induction hardening for this task was due to its flexibility in heating only the precise area required and its very short cycle time. Additionally, the martensitic transformation results in an approximately 4.3% increase in specific volume, thus the pattern was developed to minimize the impact on cylinder bore distortion. Induction hardening of ferrous materials entails three basic steps; heating to the austenitizing temperature; holding to fully convert the structure to austenite; and rapidly cooling to convert the austenite to martensite. In addition, many parts are subsequently tempered to improve toughness.

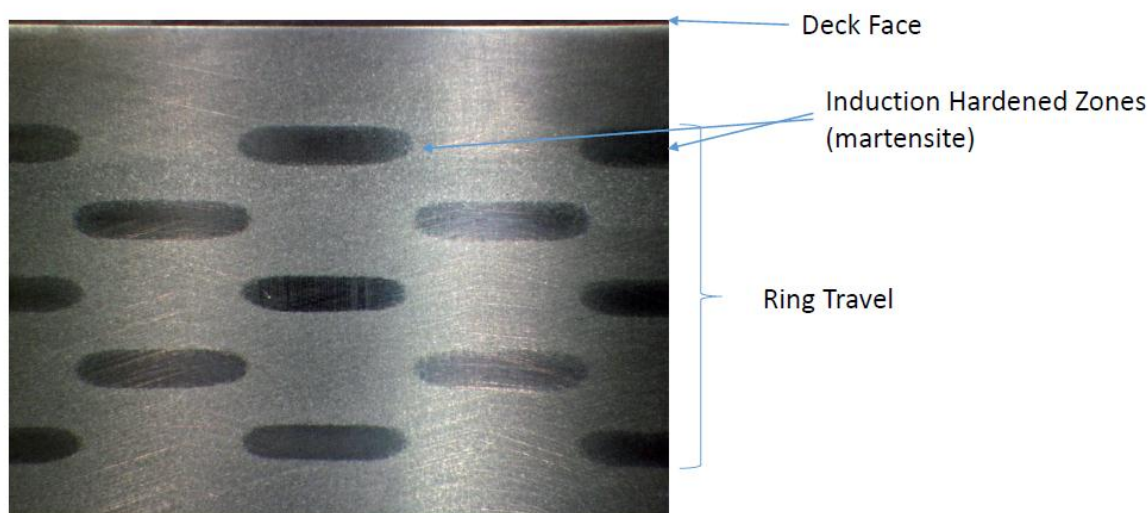


Figure 1: Pattern of Induction Hardened Zones (Ovals) on the Honed Bore Surface

**1.2 Symbols.** Not applicable.

**1.3 Applicability.** Response to induction hardening is strongly influenced by initial process design parameters in addition to the following variables:

- Incoming Material: composition, microstructure, residual stress.
- Part Dimensions: bore wall variation: thickness, diameter, cylindricity.
- Process Control: coil-to-part clearance, power input, timing, quench water.
- Documentation: hardened structure pattern, case depth.

This specification is limited to assessing and verifying the effectiveness of the hardening/tempering process in producing the microstructure, hardness and pattern of transformed microstructure on the bore inner circumference.

**1.4 Remarks.** Appendix A contains the description of the incoming block material that has been found to satisfactorily respond to induction hardening, including composition, microstructure and hardness.

## 2 References

**Note:** Only the latest approved standards are applicable unless otherwise specified.

### 2.1 External Standards/Specifications.

ASTM A 247-10                      CQI-9                      ISO 945

### 2.2 GM Standards/Specifications.

GMW4                      GMW3059

## 3 Requirements

### 3.1 Block Casting.

**3.1.1 Cylinder Bore Wall Microstructure Verification.** Bore wall microstructure to be verified by casting plant.

**Location:** Cylinder 1 bore strip for microstructure analysis – see Figure 2. Verify graphite type and size, minimum 50% Type A and size 4 to 7 per ISO 945 with the remainder being Types B, D or E. Type C graphite or any coarse, thick graphite of any type is not allowed. Etch and measure to determine matrix is > 95% fine lamellar pearlite (ferrite, carbides and steadite < 5%).

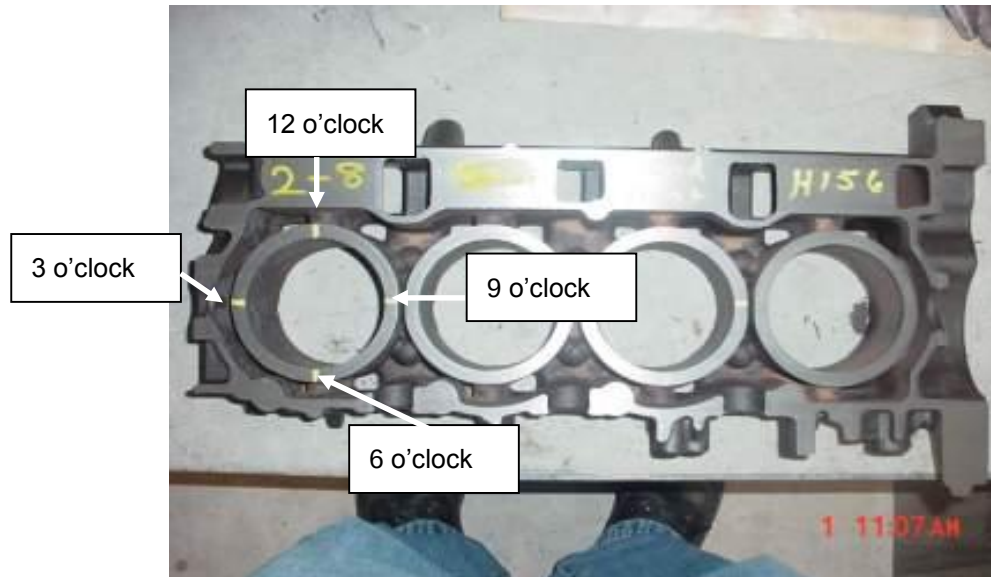


**Figure 2: Example of Head Deck Sectioned for Microstructure and Bore Wall Hardness Check on Bore No. 1**

**3.1.2 Cylinder Bore Thickness Variation.** The local temperature distribution during induction hardening is strongly influenced by the power input, the distance between the coil and the work piece, the thermal conductivity of the work piece and the geometry of the work piece. The latter is strongly influenced by variations in bore wall thickness due primarily to core shift during the casting process. The following procedure is to be done on two castings per cast date to verify bore wall dimensions. Additionally, the bore hardness is checked at the same time to verify the local microstructure after stress-relief heat treatment.

**3.1.2.1 Measurement Procedure.** Select 2 of the 4 verification blocks that have different pattern/serial numbers for cut up.

**3.1.2.1.1** Record Corresponding jacket slab and crankcase core numbers. The head deck must be cut between 90 mm to 100 mm down from the top of the deck.



**Note:** Position clocking is reversed because view is from beneath the head deck.

**Figure 3: Location of Bore Thickness Measurement on Section 90 mm to 100 mm Below the Head Deck with Bores 2, 4, 6 and 8**

**3.1.2.1.2** Measure the wall thickness of cylinder bores 1, 2, 7 and 8 at the 12, 3, 6 and 9 o'clock positions around each of the designated bores (Figure 3). Compare the 12 and 6 positions and the 3 and 9 positions.

**Specification:** Less than 4.5 mm difference.

**Reaction Limits:**

- < 2 mm: No action required.
- $\geq 2$  mm and  $\leq 4.5$  mm: Notify casting plant.
- > 4.5 mm: Stop shipping parts.

**3.2 Machined Dimensions.** The response of gray iron to induction hardening is sensitive to the distance of the workpiece from the induction coil, thus the dimensions of the machined and pre-honed cylinder bore must be held to tight tolerances to maintain repeatable workpiece to coil dimensions over the entire production run between coil changes. The bores are 100% gaged and cylinder bore location is verified 1/day prior to induction hardening. Nominal and tolerances of required dimensions are given in Table 1.

**Table 1: Cylinder Bore Dimensional Requirements Prior to Induction Hardening**

|               |                          |
|---------------|--------------------------|
| Bore Diameter | 102.94 mm $\pm$ 0.015 mm |
| Roundness     | 0.01                     |
| Cylindricity  | 20 $\mu$ m               |

**Measuring Position:** 15 mm, 80 mm and 150 mm from fire deck.

**3.3 Induction Hardened Structure.**

**3.3.1 Pattern.** The 6.6 L Duramax engine has a pattern of 5 rows of 12 circumferentially and equally spaced "ovals" of induction hardening near the top of each cylinder bore (see Table 2). The reason is to provide piston ring travel wear resistance while minimizing bore distortion. The material in the "ovals" is heated by induction coils above the transition temperature to change pearlite to austenite. After transformation it is quenched to transform the austenite to martensite.