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Quench system monitoring requirements in AMS 2759G

Determining the minimum hardness required by AMS 2759G requires attention to the specific hardenability curve of the specimen material and proper equipment maintenance.

AMS 2759G Heat Treatment of Steel Parts, General Requirements [1] was adopted April 23, 2019. This important aerospace specification governs the heat treatment of aerospace parts and incorporates a number of changes related to testing the quenchant and, most importantly, the quenching system. Previously, this specification only focused on the quenchant and did not look at the entire quench system, which includes the quenchant, but also includes material handling and agitation.

The Aerospace Materials Engineering Committee (AMEC) of SAE decided to examine the entire quenching process and quench system instead of focusing strictly on the quenchant. The quenchant, agitation, and material-handling system (quench system) must operate together to ensure that parts are quenched properly. Agitation and material handling are difficult to quantify. The quenchant can be suitably described by various testing methods, including cooling curves (ASTM D6200 [2]). However, there is presently no method to qualify agitation, as the presence of different parts can affect the fluid flow. In light of this, AMEC decided to base the quality of the quench system on the basis of achieving acceptable quenching of specific bars of material. The test materials are one of the following:

- SAE 4130 round bar, a minimum of 1.5" (3.81 cm) long, and 0.5" (1.27 cm) nominal diameter.
- SAE 4140 round bar, a minimum of 4.5" (11.43 cm) long, and 1.5" (3.81 cm) nominal diameter.
- SAE 4330V round bar, a minimum of 7.5" (19.05 cm) long, and 2.5" (6.35 cm) nominal diameter.

These specimens, after quenching, shall have a hardness "not less than the hardness on the end-quench hardenability curve corresponding to the diameter of the specimen when tested in accordance with ASTM A304." [2] [3]

These samples are to be run quarterly with either a typical or simulated production load processed to AMS 2759 requirements. After the parts are quenched, a 0.5" (12.5 mm) segment from the center of the specimen is to be removed from the test specimen in the as-quenched condition.

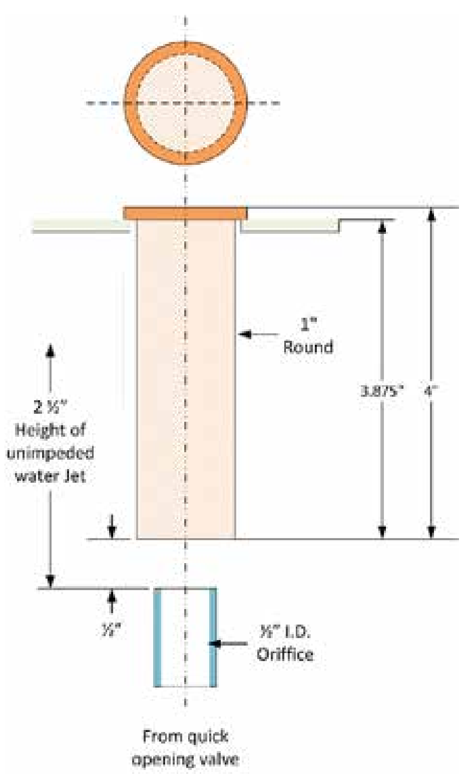

Figure 1: Schematic of the Jominy End-Quench Apparatus.

JOMINY END-QUENCH TESTING

The Jominy end-quench test, is a rather ingenious test invented by Walter E. Jominy (1893-1976) and A.L. Boegehold [4]. In this test, a round steel bar 1" in diameter by 4" long is heated to 1,600°F. The bar is then removed from the furnace and placed in a special fixture. The special fixture allows water to strike one end of the sample. This quenched end experiences the fastest quench rate, and distances from the quenched end (usually measured in n/16") cool progressively slower. Two flats are ground in the bar, and hardness is measured as a function of the distance from the quenched end. The basic apparatus is shown in Figure 1.

This test forms the basic foundation for the measurement of hardenability in steels. If you remember, hardenability is not how hard the steel gets when quenched but rather how deeply it is hardened.

Interestingly, this test has been used for aluminum [5] and titanium [6] to characterize microstructure as a function of quench rate.

The hardness data is typically plotted as a function of distance from the quenched end on standardized forms [3]. Figure 2 is an illustration of the form from ASTM A304 [3].

There are several things to notice in this graph. The first things to notice are the upper and lower hardenability bands for the specific alloy. In general, the alloy, when tested, must lie between the upper and lower limits of the hardenability curve.

The upper and lower hardenability limits are in HRC as a function of distance from the quenched end of the Jominy end-quench specimen. Due to end effects, the hardness measurements are usually started at n=2/16". Occasionally, the end quench hardness at n=0 is taken on the end of the specimen.

The second thing to notice is the table at the top of the figure showing the diameters of rounds with the same as-quenched hardness for a mild water quench and a mild oil quench. Radial distances of surface (r=R), three-quarter radius (r = 3/4R), and the center of the bar (r = 0) are described. While not clear in the specification, it is these values that are used to establish the acceptable quench system limits in AMS 2759.

The distances relating to the diameters of bars with the same as-quenched hardness remain the same and are a function of the distance from the quenched end. Plotting the bar diameters for surface, 3/4 radius, and center for a mild oil quench as a function of distance from the quenched end yields a graph (Figure 3). We will use this graph to establish the Jominy distances for each of the bar diameters cited above, in AMS 2759.

Ignoring for a moment the specific speci-

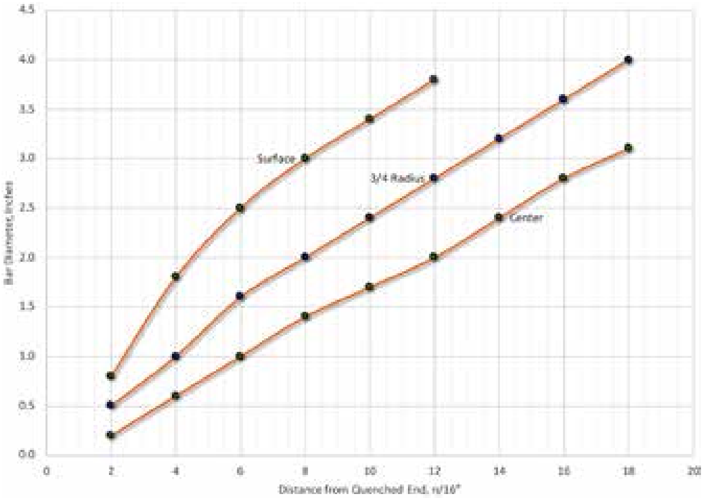

Figure 2: Typical Jominy End Quench Data of SAE 4140H plotted in accordance with ASTM A304 [3].

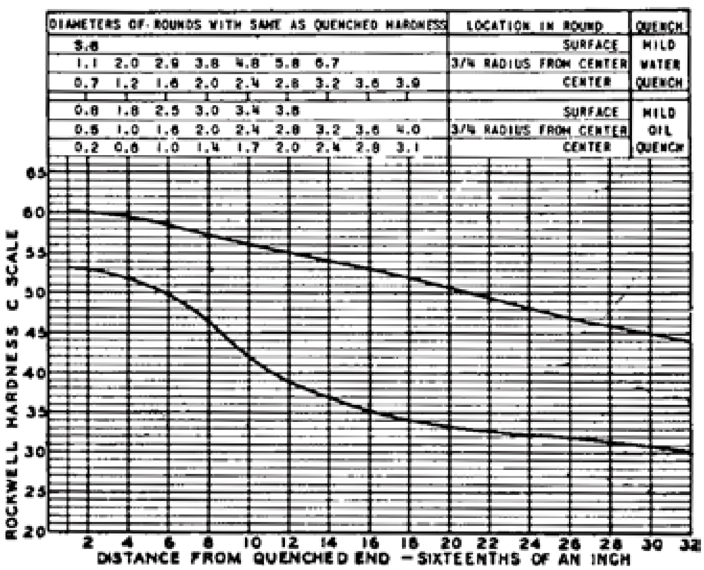

Figure 3: Diameters of Rounds with the same as-quenched hardness, as a function of the distance from the quenched end for ASTM A304 [3].

	SAE 4130	SAE 4140	SAE 4330V
Bar Diameter	0.5	1.5	2.5
Jominy Distance at Center, n/16"	3.5	9.0	14.5
Jominy Distance at 3/4 Radius, n/16"	–	6.0	–
Jominy Distance at Surface, n/16"	–	–	–

Table 1: Specific positions on the Jominy end-quench corresponding to the Quench System Severity test in AMS 2759.

men hardenability used in AMS 2759, it is possible to detail the limits of minimum hardness and the location on the Jominy end-quench curve. Using the graph in Figure 3, we remember that the SAE 4130 bar has a specimen size of 0.5". These specimens, after quenching, shall have a hardness "not less than the hardness on the end-quench hardenability curve corresponding to the diameter of the specimen when tested in accordance with ASTM A304" [2] [3]. Where is the Jominy distance corresponding to this requirement?

Looking at Figure 3, we see that the bar diameter, 0.5", measured at the center of the bar, corresponds to a Jominy distance of J = 3.5/16" for SAE 4130. For the SAE 4330V bar, it has a nominal diameter of 2.5". Looking at Figure 3 for the distance corresponding to the center hardness for a bar 2.5" in diameter, this corresponds to a distance from the quenched end of 14.5/16".

The case for SAE 4140H (Figure 2) is a bit different. In this case, two hardnesses at different locations are specified. Also, the hardness at the center of the bar shall not be less than HRC 44, and the 3/4 Radius shall not be less than HRC 50. However, while appearing to be more stringent, the test requirement is not more stringent.

Looking at the Jominy curve for SAE 4140H with a diameter of 1.5", the center of the bar corresponds to J = 9/16", and the 3/4 Radius corresponds to a Jominy distance of J= 6/16". Taking the hardness of HRC 44 at the center, and HRC 50 at the 3/4 Radius, we see that these values correspond to the minimum hardenability curves for SAE 4140.

The values for the specific Jominy end-quench distances are specific in Table 1.

When raw material is obtained for performing the quench system monitoring test, the user should request the specific Jominy end-quench data for the heat of steel. Using the Jominy distances in the specific heat lot certification, the minimum acceptable hardness can be determined. If the hardness, when tested quarterly, falls below the minimum hardness, then corrective action should be taken. This corrective action could be maintenance on agitators or material handling systems. This also assumes that the quenchant used meets the requirements and is similar to original specifications. As long as the proper oil has been chosen, then the quenchant is usually not the problem.

CONCLUSIONS

In this short article, the methodology for determining the minimum hardness required by AMS 2759 for the quench system monitoring is described. It requires attention to the specific hardenability curve of the specimen material, as well as proper maintenance of equipment.

This is the first attempt to ensure that the entire quench system (quenchant, agitation, and handling) is up to the task of heat-treating aerospace components.

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