Attachment 5
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U.S. Nuclear Regulatory Commission
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SUBJECT: Hardness Tests on Assorted Specimens

Dear Roger:

Hardness tests were performed to determine whether the material samples met the mechanical requirements of the appropriate ASTM specification. In some cases the requirements include a minimum and maximum tensile strength, a minimum yield strength, and minimum elongation requirements. These should be determined by uniaxial tensile tests. However, because of limitations on the amount of material available hardness tests offered the only means to estimate these properties. The relationship between hardness and flow stress is well known (see, e.g., F. McClintock and A. Argon, Mechanical Behavior of Materials).

Specimens were mounted and polished to remove ~30 mils of the most severely deformed material from the surface. Vickers hardness tests were then performed using a 163° pyramid indenter with a loading force of 30 kg. Some exploratory tests showed that the particular choice of the loading force had little effect on the measured hardness values. The diagonal of the impression d_1 was measured and the Vickers hardness computed from

$$V = \frac{P}{A_C} = \frac{1.854P}{d_1^2} \quad (P \text{ kg}, d_1 \text{ mm}) \qquad (1)$$

where P is the loading force and A_C the contact area. The Meyer-Vickers hardness M_V which is based on the projected area A_p instead of the contact area A_C was computed from

$$M_V = \frac{2P}{d_1^2} = \frac{V}{0.927} \text{ kg/mm}^2 \qquad (2)$$

Since the Meyer-Vickers hardness generally is a better representation of the average pressure on the area of contact it was used to compute the flow stress S_F from

$$M_V = 3.2\ S_F \qquad (3)$$

The results are tabulated below with S_F expressed in the usual American engineering units of ksi (1 kg/mm^2 = 1.422 ksi).

Item	ASTM Specifications*	Measured Hardness		Flow Stress
		V**	M_V†	S_F††
Plate ASTM A36 Sample # 36	Tensile Strength 58-80 ksi Minimum Yield Point 36 ksi	137	148	66 ksi
Bolt ASTM A307 Grade A This is the bolt that is too hard. Sample # 38	Tensile Requirement 60 ksi Brinell Hardness 121-241 min max Rockwell Hardness B69-B100 min max	303	327	145 ksi
Nut ASTM A563 Grade A Sample # 39	Proof Load Stress 68 ksi Brinell Hardness 116-302 min max Rockwell Hardness B69-C32 min max	203	219	97 ksi
Washer Unknown	This data not used since no spec. given for washers.	99	107	48 ksi

*Parts of the required specifications. See "Annual Book of ASTM Standards" for full specifications.

**Vickers hardness, Eq. (1).

†Meyers hardness, Eq. (2). ††Eq. (3).

The flow stress obtained for the A16 plate is consistant with the tensile strength requirements for this material. The requirements for the bolt and nut are given in terms of Brinnell hardness rather than Vickers hardness. However, the two are approximately equal; a more accurate comparison of the two hardness measurements can be obtained from the ASM Metals Handbook, Vol. I, p. 1234. According to these results:

Vickers	is equivalent to	Brinnell	or	Rockwell
303		287		B106
203		193		B92
99		94		B56

Thus the nut seems to meet the hardness specification and the calculated flow stress is consistent with the proof load stress. However, the bolt appears to exceed the hardness specification which would tend to reduce the toughness on the bolt. We have made measurements on the washer, but it is not clear what specifications it should meet.

I hope this information will be of help to you. As before the measurements and calculations presented here were actually performed by J. Y. Park and D. Perkins.

Sincerely,

William J. Shack
Materials Science and
Technology Division

WJS:dkm

cc: J. Y. Park
D. Perkins
R. W. Weeks