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EFFECTS OF HARDNESS ON PINTLE ROD PERFORMANCE IN THE UNIVERSAL AND RETAINED GAS SAMPLERS

R.M. Boger

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Abstract:

Interaction between hardness' of the pintle rods and the retainer rings used in the core samplers samplers is investigated. It is found that ordinary Rockwell C measurements are not sufficient and superficial hardness instruments are recommended to verify hardness since in-production hardness' of pintle rods is found to vary widely and probably leads to some premature release of pistons in samplers.

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EFFECTS OF HARDNESS ON PINTLE ROD PERFORMANCE
IN THE UNIVERSAL AND RETAINED GAS SAMPLERS
RPP-5114

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1.0 INTRODUCTION

Characterization of the waste in Hanford underground storage tanks is necessary to maintain safe storage of the waste and to support design/planning of efforts to convert the waste into glass. Characterization of the waste is accomplished by drawing samples from the tanks and analyzing them at the analytical laboratory. Various methods are employed to obtain samples from the tanks based on the sampling objectives. Sometimes full core profiles of the waste are required. When this is the case, samples are taken with specially designed metal samplers which are operated by means of the Core Sampling Trucks.

There are four types of core samplers (Refs. 1, 2) used to obtain core samples, but the theory of operation is the same regardless of the type.

In all of the samplers, a piston is connected to a pintle rod which holds the piston stationary during filling of the sampler. At the end of the filling stroke the pintle rod needs to be detached from the piston to allow the handling equipment (i.e., the remote latch unit) access to the top of the sampler. The pintle rod is connected to the piston by means of a sheet metal retainer ring (see Figs. 1 and 2). The ring is press-fit to the end of the pintle rod and captured by the piston in a groove near the top of the piston. The top surface of the groove, which interfaces with the retainer ring, contacts the outer edge of the retainer ring. In this way, force between the piston and the pintle rod deforms the ring (slightly) so that it grabs the rod.

At the end of the sampling stroke, the piston is released from the pintle rod by the release disk. The bottom of the release disk, which is shaped as a knife edge, transfers the force from the retainer ring's periphery to its interface/intersection with the pintle rod. When force is applied at this point the knife edge tends to pry the retainer ring from the pintle rod thus, releasing the piston.

In early FY'99 the samplers used in sampling waste tanks displayed a serious failure mode. After 3 years of successful operation, the piston-pintle rod connection of the sampler design was found to be unreliable--some pistons would not stay attached to the pintle rod; others would not release. Characterization Engineering identified the problem to be associated with the control of pintle rod surface hardness. A heat treatment step was introduced into the fabrication of samplers which has greatly improved the piston-pintle rod performance.

A study into the superficial hardness of specimen pintle rods and retainer rings suggests that the current solution to the problem may not be completely satisfactory. It is recommended that the pintle rod-piston connection design be improved.

As part of the failure investigation, an in-depth study of the ability to reliably harden the pintle rod was initiated. This report presents the results of this investigation.

FIGURE 1

T99220SS-126

DATE E.C.O REVISIONS

8-11-89 1374 .035/.025 WAS .030/.020

10-9-98 430846 REDESIGN ON CAD, 1797.173 DESIGNATED SPC DIMENSION (S)

ASSEMBLY TOOL HEAD

PATENTED

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MATERIAL

306 SERIES STAINLESS STEEL

THICKNESS .022 HEAT TREAT

SCALE
1"=1"

CLASS OF 1
FINISH ROCK. 11/2 HARD

DRAWN 3H/VC4
DATE 6-8-83

SPECIAL FEATURES
.187 STUD DIA.

CLASSIFICATION OF DIMENSIONS

* DENOTES SET-UP DIMENSIONS

ALL OTHERS-MINOR DIMENSIONS

THIRD ANGLE PROJECTION

APPROVED JHE
1 ST. PROD.

T99220SS-126
THIN WALL STUD RECEIVER

EATON ENGINEERED FASTENERS

TINNERMAN BRAND

EATON CORPORATION
ENGINEERED FASTENERS OPERATIONS
MASSILLON PLANT 210-616 ST. N.W.
MASSILLON, OHIO 44864

FIGURE 2
RETAINER RING

2.0 SUMMARY

Hardness testing of the current pintle rod material and of samples of old material suggest that the new material is harder than that used for sampler fabrication in 1996, probably caused by small differences in manufacturing of the rod material.

In a number of tests of the current pintle rod material, it was observed that the piston was released too easily. The old material performed successful for three years. Fully annealed pintle rods were observed to hold on to the retainer rings too tightly--sometime not releasing at all.

Heat treated samples with a variety of heat treating schedules were obtained. Testing revealed that heat treatment of $1100 \pm 50^{\circ}\text{F}$ for $3 \pm .3$ hours provided pintle rods with the most satisfactory performance. Although, the hold and release parameters of these pintle rods were satisfactory, not all of the tested specimens met the "fail force" criteria (less than 200 pounds) The performance specification is described in Appendix A.1.

The tests were performed by installing a new retainer ring on to a test pintle rod specimen and measuring the force to pull it off with the Satec machine in the 306 Building.

The superficial hardness of the pintle rods and retainer rings was measured on a variety of rods (33 pcs) with a variety of heat treatments and surface conditions. Hardness of rings (23 pcs) was also tested. It is observed that for pintle rods of a common heat treat temperature, the minimum hardness readings are generally lower as the heat-treat temperature goes up. However, the maximum hardness readings are greater than any retainer ring.

A large fraction of the pintle rods heat treated to 1150°F , or more, are softer than most of the retainer rings. Based on the concept that the rod should be somewhat softer than the retainer ring for proper operation, it is expected that heat treating to 1150°F will produce a significant fraction of pintle rod-ring pairs that operate properly. At the same time, heat treating to temperatures greater than 1150°F could produce a larger percentage of pintle rod-ring pairs that grip too tightly.

The sampler drawing has been ECN'd to require heat treating (and not annealing) of pintle rods. Beside heat treatment, the pintle rod-piston connection is now tested at several times during the life of the sampler. To date performance has been reported to be much improved, however, there have been some unsubstantiated reports of failure-to-hold. It has been postulated that the interference fit between the retainer ring and the pintle rod relaxes over time, for example, by means of metal creep.

3.0 DESCRIPTION OF TESTS

3.1 PULL TEST

Samples of currently on-hand-pintle rod material were sent to Beaver Heat Treating®, Portland, OR who treated the samples with a variety of heat treating schedules: 1050°F , 1100°F , 1150°F , and 1250°F . All of the heat treatments were held at temperature for three hours. Cooling was performed in an inert atmosphere. Beaver's measurement of the hardness of the samples were included with the temperature/time data received from Beaver.

The samples were tested on the Satec machine in 305/300. The tests were performed by installing a new retainer ring on to a test pintle rod specimen and then the force to pull the ring off, either with or without the release disk, was measured with the Satec machine. Since a retainer ring can be used only once, each of the pull tests on an individual pintle rod specimen are performed with a different retainer ring.

3.2 SUPERFICIAL HARDNESS TESTING

As discussed in Appendix A.2, the validity of the hardness values submitted by Beaver may be questioned. The readings were taken with a Rockwell C instrument which is not expected to provide reliable results on rods as small as the pintle rods. Improved hardness readings can be made with a superficial hardness testers.

A selection of 33 pintle rods and 23 retainer rings were studied utilizing a superficial hardness tester (Officine Galileo, Firenze, Italy). A description of superficial hardness testing and its advantages can be found in Appendix A.2. The samples were drawn from: the heat-treated specimens prepared by Beaver Heat Treating®, failures from the field, failures from manufacturing and non-failures. The sources of the pintle rods and rings are summarized in Section 4 and greater detail on the rod's and retainer ring's histories can be found in the appendices.

Pintle rods in the universal sampler have their ends roughened ostensibly to improve the holding force. The samples obtained from Beaver Heat Treating were tested without roughening, i.e., smooth. However, three samples were tested with their ends knurled.

Hardness measurements were taken at a number of locations on the test pieces. Also, the different surface preparations were hardness-tested. Besides the roughening of the pintle rod ends with a thread chasing file (Ref. 1) tests were conducted on knurling, and machine brushing. In cases of used pintle rods, the original retainer ring left a scrapped region on the end of the rod when it was pulled off. Heat treated pintle rod samples from Beaver are discolored (lightly oxidized). Bluish and brownish surfaces are found on the samples depending upon the heat treat cool-down atmosphere. Details of the tests can be found in the appendices referenced.

3.3 RETAINER RINGS

The manufacturer of the retainer ring (Eaton Industries®, Cleveland, OH) was contacted and the design of the piston-pintle rod connection was discussed with their applications engineers. Samples of failed rings were sent to Eaton for analysis.

Rings from two failed samplers and from one old sampler (which operated correctly) were examined microscopically. The rings were "mounted" and sectioned to reveal the contour of the edge that interfaces with the pintle rod (the gripping edge). Also, the mounted specimens were analyzed for different alloy content in a scanning electron microscope.

Superficial hardness of the retainer rings was also measured.

4.0 TEST RESULTS

4.1 PULL TEST RESULTS

Pull test results are shown in Figures 3 and 4. Hardness values were provided by Beaver Heat Treating. The values were obtained with a Rockwell C instrument.

Since a retainer ring can be used only once, each of the data points in Figures 3 and 4 are taken with a different retainer ring. The force readings are presented in descending order (i.e., there is no significance associated with the abscissa). It should be observed that the forces generally overlap independent of heat treatment of the pintle specimen. No particular pattern is apparent: for example, the curve of the softest pintle (Rc=13; 1250°F) lies close to that of the hardest (Rc=22; 1050°F), see Figure 3. In Figure 3, Normal Release Force, there is some suggestion that harder pintle release more easily, except for the results of the Rc=20 specimen which is the second-softest material and has the largest release force.

As discussed in Appendix A.2, the validity of these hardness values may be questioned. The readings were taken with a Rc weight/indenter which is not expected to provide reliable results on rods as small as the pintle rods. Consequently, the hardness of the rod consistently producing forces greater than the other samples (diamond data points, Figs. 3 and 4), may not be actually be Rc=20.

Pintle rods in the universal sampler have their ends roughened ostensibly to improve the holding force. The samples in Figures 3 and 4 were tested without roughening, i.e., smooth. However, three samples were tested with their ends knurled. As can be seen in Figures 3 and 4 there is not much difference in performance.

In spite of a lack of a clear association between heat treatment and release forces, it should be pointed out that all of the normal release forces are less than 100 pounds and are, thus, "in spec" according to Appendix A.1. Also, it should be noted that most of the emergency pull-out forces (Fig. 4) are above 200 pounds and, thus, "out of spec".

This excessive emergency pull-out force is considered to be a relatively small risk to sampling operations. Such high forces would be expected of the drill truck draw works only if some other failure occurred down in the drill string which would seize the piston and keep it from contacting the spring stops.

4.2 SUPERFICIAL HARDNESS TEST RESULTS

Results of superficial hardness testing are summarized in Table I. Details of the testing/results are found in the appendices which are called-out in the Table. A description of the rod/ring sample is given along with an identification number. For each sample the range of superficial hardness results is given.

The results are graphically illustrated in Figure 5. The ranges of hardness readings for the different heat-treated samples versus the heat treatment temperatures are displayed. Readings were taken at a wide variety of locations. The readings at similar surface conditions are grouped into a common vertical line (with median reading marked with a circle, diamond,

1/21/99

Pintle Rod Pull Testing Without Release Disk (non-sequential)

FIGURE 3
RELEASE FORCE WITH RELEASE DISK

Pintle Rod Pull Testing With Release Disk (non-sequential)

Keith Witwer

FIGURE 4
EMERGENCY PULL-OFF FORCE

TABLE I

Sample No	Description	Characteristic	Hardness	Comment	Reference Appendix
PINTLE RODS					
1	Fresh, old materia C.10, from 272W/200 shop	Rod (failed)	Rc=22* Rc=24 to 25** 15N=72 to 73 (Rc=24 to 26)		C.1, C.2, C.4, C.5
2	New Rev 0 material	Rod (worked well)	Rc=20.2* Rc=26 to 27** 15N=73 to 74 (Rc=26 to 27)		C.1, C.2, C.5
3	Like #2, but harder per 272W shop	Rod (worked well)	Rc=23.5* Rc=25 to 29** 15N=72 to 74 (Rc=24 to 27)	Rods 1,2,3 ranged from (Rc=24 to 30)	C.1, C.2, C.5
98-016	Not heat treated Removed from sampler	Failed	15N=71 to 73 (Rc= 22.5 to 26.5)	Had ring (1)	C.9, C.11
98-013	Not heat treated Removed from sampler	Failed	15N=69 to 74 (Rc=20 to 24)	Had ring (1)	C.9, C.11
98-010	Not heat treated Removed from sampler	Failed	15N=71 (Rc=23)	Had ring	C.9
98-029	Not heat treated Removed from sampler	Failed	15N=71 (Rc=23)	Had ring	C.9
98-033	Not heat treated Removed from sampler	failed	15N=72 (Rc=24)	Had ring	C.9
98-036	Not heat treated Removed from sampler	failed	15N=70 (Rc=21)	Had ring	C.9
RT5-10	Failed Retest 5-10	No bite mark	15N=70 to 73 (Rc=21 to	Had ring (1)	C.8, C.9,

	lb. Heat Treated†	from ring	26)	Had ring (1)	C.11
98-034	Removed from Sampler Heat Treated†	failed. No bite mark from ring.	15N=70 to 74 (Rc=21 to 25)	Had ring (1)	C.8, C.9, C.11
FIT-1	Removed from Sampler Failed-in-Test. Heat Treated†	No bite mark from ring.	15N=70 (Rc=21)	Had rings (3)	C.8, C.9
4N-1	Test specimen from Beaver Heat Treating	4 notches 1050°F 3 hr	Rc=22 per Beaver 15N=74-79 (Rc=28-35)		C.7, C.6, C.10
4N-2	Test specimen from Beaver Heat Treating	4 notches 1050°F 3 hrs	Rc=22 per Beaver 15N=72-74 (Rc=23-31)		C.7, C.6, C.10
5N-1	Test specimen from Beaver Heat Treating	5 notches 1150°F 3 hrs	Rc=16-17 per Beaver 15N=72 (Rc=23)		C.7, C.6, C.10
5N-2	Test specimen from Beaver Heat Treating	5 notches 1150°F 3 hrs	Rc=16-17 per Beaver 15N=69 (Rc=20)		C.7, C.6, C.10
6N-1	Test specimen from Beaver Heat Treating	6 notches 1250°F 3 hrs	Rc=13 per Beaver 15N=61-74 (Rc=17-27)		C.7, C.6, C.10
6N-2	Test specimen from Beaver Heat Treating	6 notches 1250°F 3 hrs	Rc=13 per Beaver 15N=66-80 (Rc=17-40)		C.7, C.6, C.10
7N-1	Test specimen from Beaver Heat Treating	7 notches 1100°F 3 hrs	Rc=20-21 per Beaver 15N=71-74 (Rc=23-28)		C.7, C.6, C.10
7N-2	Test specimen from Beaver Heat Treating	7 notches 1100°F 3 hrs	Rc=20-21 per Beaver 15N=73-74 (Rc=26-28)		C.6, C.10
LB-1	Heat treated at Beaver	1100°F 3 hr	15N=68-71 (Rc=20-23)		C.7, C.6, C.10
LB-2	Heat treated at Beaver	1100°F 3 hr			C.6
LB-3	Heat treated at Beaver	1100°F 3 hr			C.6
LB-4	Heat treated at Beaver	1100°F 3 hr			C.6

LB-5	Heat treated at Beaver	1100°F 3 hr			C.7, C.6, C.10
B-1	Heat treated at Beaver	1100°F 3 hr	15N=69-70 (Rc=20-22)		C.7, C.6, C.10
B-2	Heat treated at Beaver	1100°F 3 hr	15N=70 (Rc=21)		C.7, C.6, C.10
B-3	Heat treated at Beaver	1100°F 3 hr			C.6
B-4	Heat treated at Beaver	1100°F 3 hr			C.6
B-5	Heat treated at Beaver	1100°F 3 hr			C.6
G-1	Annealed at 306/300	Red hot	15N=52-71 (Rc=<15-26)		C.7
G-2	Annealed at 306/300	Red hot	15N=55-72 (Rc=<15-24)		C.7
G-3	Annealed at 306/300	Red hot	15N=55-71 (Rc=<15-23)		C.7

RETAINING RINGS

1	Failed	Ring	15N=66 (Rc=18)		C.1, C.3, C.2,
2	Failed	Ring	15N=72 (Rc=25)		C.1, C.3, C.2
3	Failed	Ring	15N=71 (Rc=22)		C.1, C.3, C.2
4	New, production	Ring	15N=74 (Rc=29)		C.1, C.3, C.2
5	New, production	Ring	15N=73 (Rc=28)		C.1, C.3, C.2
6	New, production	Ring	15N=74 (Rc=28)		C.1, C.3, C.2
7	New, production	Ring	15N=76 (Rc=32)		C.3
8	New, production	Ring	15N=73 (Rc=26)		C.3
9	New, production	Ring	15N=73 (Rc=27)		C.3
10	New, production	Ring	15N=75 (Rc=30)		C.3
11	New, production	Ring	15N=76 (Rc=33)		C.3
12	New, production	Ring	15N=74 (Rc=29)		C.3
FIT-1,1	Failed during assembly		15N=73 (Rc=26)	These three rings were used trying to make rod FIT-1 work	C.9
FIT-1,2	Failed during assembly		15N=72.5 (Rc=25)		C.9

FIT-1,3	Failed during assembly		15N=72 (Rc=24.5)		C.9
RT5-10	Failed during assembly		15N=73 (Rc=26)		C.9
98-016	Removed from failed sampler with pintle rod		15N=73 (Rc=26.5)		C.9
98-013	Removed from failed sampler with pintle rod		15N=73 (Rc=27)		C.9
98-010	Removed from failed sampler with pintle rod		15N=71 (Rc=23)		C.9
98-029	Removed from failed sampler with pintle rod		15N=71 (Rc=23.5)		C.9
98-033	Removed from failed sampler with pintle rod		15N=72 (Rc=24)		C.9
98-034	Removed from failed sampler with pintle rod		15N=71 (Rc=22)		C.9
98-036	Removed from failed sampler with pintle rod		15N=70 (Rc=20.5)		C.9

*taken with Rockwell hardness machines at the 272W shop
 ** Taken with hardness machine at 306/300 area lab. Superficial hardness readings converted to the Rockwell C scale are given in parenthesis.
 +1100 ± 50°F for 3 ± .3 hours

SUPERFICIAL HARDNESS VS STRESS RELIEF TEMPERATURE

FIGURE 5
SUPERFICIAL HARDNESS RESULTS

etc.) Samples which were heat treated at a common temperature are grouped in a common "cloud".

The hardness readings were taken with the superficial hardness tester and the readings were converted to the equivalent Rc readings. It should be noted that the hardness reading obtained by Beaver Heat Treating, which were obtained with an ordinary Rockwell C hardness instrument, are also plotted in Figure 5. The Beaver readings are consistently below the superficial readings, presumably, because the rod diameters are too small for proper use of the Rockwell C indenter/weights.

Figure 5 shows that the minimum hardness readings are generally lower as the heat-treat temperature goes up. However, the maximum readings are all on the order of Rc=35.

4.3 RETAINER RING RESULTS

In communication with the ring factory (Eaton Industries, Cleveland, OH) their applications service suggests that the ring was not designed to be used in a "hold and remove" application. The ring was intended to be put on and left on. Samples of failed rings were sent to Eaton who found nothing wrong with them.

Results of the photomicroscopy study of the rings' interfacing edge are shown in Figure 6. The rings are cut through the centerline and the cut surface (.020 width) is shown magnified by X100. The photo designated "97" is of a ring that functioned properly. Photos marked "98" are from the marginal performance population. No difference between the rings that fail and the one that worked properly is apparent.

Elemental analysis of the rings is shown in Figures 7.1, 7.2 and 7.3. Figure 7.1 illustrates the composition of old rings which are from the time period during which the piston-pintle rod connections worked well. Figures 7.2 and 7.3 are newer from the period of time of the piston-pintle rod failures. Both the failed rings and the functional ring have, essentially, the same elemental make-up.

Superficial hardness reading of the retainer rings suggests that the ring hardness varies over a great range. At the left edge of Figure 5, the hardness range observed for the retainer rings is indicated. It can be seen that the maximum hardness for pintle rods is greater than any retainer ring. But, some of the pintle rods which have been heat treated to 1150°F, or more, are softer than most of the retainer rings. Based on the concept that the pintle rod should be somewhat softer than the retainer ring for proper operation, Figure 5 suggests that heat treating to 1150°F will produce a significant fraction of pintle rod-ring pairs that operate properly. However, a fraction of the pintle rods will be expected to be too hard to engage the retainer ring sufficiently.

At the same time, heat treating to temperatures greater than 1150°F could produce a larger percentage of pintle rod-ring pairs that grip tightly. But, as was observed with the retained gas sampler, it may be difficult to release the grip with the release disk if the heat treatment temperature is too high.

BEST AVAILABLE COPY

X200

97

1198

100X

100X

1298

FIGURE 6

PHOTOMICROGRAPH OF RETAINER RING INTERFACE EDGES

Section of Edge. Irregular Edge is Outer Edge of Hole. Ring designated "97" is from the batches of rings the functioned properly. The "1298" and "1198" are from batches that malfunctioned. Essentially no difference is apparent among the samples.

BATTELLE-PNNL PSL/SEM

TUE 29-DEC-98 16:06

Cursor:10.230keV = 36

ROI (1) 0.000: 0.000

FIGURE 7.1
RETAINER RING ELEMENTAL ANALYSIS
Ring from old stock (worked)

Cursor:10.230keV = 58

ROI (1) 0.000: 0.000

FIGURE 7.2
RETAINER RING ELEMENTAL ANALYSIS
Ring from New Stock (problematical)

BATTELLE-PNNL PSL/SEM

TUE 29-DEC-98 15:57

Cursor:10.230keV = 56

ROI (1) 0.000: 0.000

FIGURE 7.3
RETAIER RING ELEMENTAL ANALYSIS
Ring from New Stock (problematical)

5.0 CONCLUSION

The severity of the failure of piston-pintle rod connection in samplers has largely been mitigated by heat treating the pintle rod as part of the fabrication process. However, room for improvement appears to be available:

- emergency pull-out force is excessive for a significant fraction of samplers
- failure-to-hold failures seem to be not completely eradicated.
- potentially aging the samplers in storage contributes to creep which could induce early release failures.
- pintle rod hardness depends upon a relatively precise heat treatment procedure and could be being influenced by other, unknown, factors
- the metallurgical properties of the retainer ring are relatively out-of-control since the manufacturer does not intend for them to be used in an install-and-remove application such as the piston-pintle rod connection.
- Because of these uncertainties the piston-pintle rod connection should be redesigned to reduce its dependence on material properties.

6.0 REFERENCES

- 6.1 Universal Sampler Drawing H-2-690140
- 6.2 Retained Gas Sampler Drawing H-2-821608
- 6.3 RFP-4782 Development of the Pintle Release Fork Mechanism, 1999
- 6.4 Hardness Tester and Accessory Instruction Book, Officine Galileo®, Firenze, Italy (1977)
- 6.5 ANS Z115.6 E18-74 "Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials"

APPENDIX

A.1 PERFORMANCE SPECIFICATION

The piston-pintle rod holding force requirement must be at least 120 pounds so that the piston does not come loose under the action of the hydrostatic head forces experienced during sampler change out.

The fail force must not be greater than 200 pounds because if the piston were to get stuck in the sampler below the spring stops, the core sample truck draw works would have to force the pintle rod out of the piston. Forcing it out with more than 200 pounds would damage the core sample truck draw works.

A.2 HARDNESS TESTING

As explained in Reference 4, the retainer ring is designed to "bite" into the pintle rod to form the piston-pintle rod connection. If the pintle rod is too hard, or if the retainer ring is too soft, the bite may not be effective.

Measurement of retainer ring hardness presents technical difficulties because the ring is made of .02-thick material.

A.2.1 NORMAL ROCKWELL TESTERS

Rockwell hardness testers utilize a hard "indenter" which is pressed into the metal in a controlled manner. First, an initial load of 10 kg is applied pressing the indenter into the metal. Then a standard force is added (60, 100 or 150 kg depending upon the Rockwell scale) to the initial load and removed. The increase in penetration, relative to the initial indent, in multiples of 2 microns is the Rockwell hardness reading.

The standard force along with the particular indenter used distinguishes one Rockwell scale from another. For example:

Rockwell Scale	Indenter	Load (kg)
C	Diamond Cone	150
A	Diamond Cone	60
D	Diamond Cone	100
B	1/16" dia. Steel Ball	100
F	1/16" dia. Steel Ball	60

From Reference 4.

Good practice hardness testing requires a minimum thickness for the test specimens. Disturbance of the metal from the indenter should not be visible on the opposite side of the specimen. Data from Reference 5 suggests that retainer ring material (.02 thick) can not be reliably tested if it is softer than Rc=80. In other words, a normal Rockwell hardness instrument would not be suitable for testing retainer rings in the hardness range expected.

Furthermore, hardness testing of cylinders, such as the pintle rod, require a correction factor. Reference 3 gives a selection of correction factors, but none are available for rods the size of the pintle rod. The pintle rod diameter, .187", is less than the smallest, .25", for which a correction is published.

A.2.2 SUPERFICIAL HARDNESS TESTERS

A more-suitable instrument for pintle rod-retainer ring quantification would be the superficial hardness tester which uses smaller forces and smaller penetrations. The indenters are essentially the same as the normal Rockwell tester, but the initial force is 3 kg. The units of superficial hardness is in multiples of 1 micron and the scale-weight system is shown below:

Superficial Hardness Scale	Indenter	Test Load (kg)
15 N	Diamond Cone	15
30 N	Diamond Cone	30
45 N	Diamond Cone	45
15 T	1/16" dia Steel Ball	15

A.2.3 CORRECTIONS

Superficial hardness scales accommodate thinner material. Reference 5 indicates that the R15N scale is usable on .02-thick material softer than Rc=20. Also, diameter corrections are given in Reference 5 for pintle rod diameters.

A.2.4 CONVERSIONS

Material specimens of given hardness will "read" differently on the different Rockwell scales. For example, a metal may read Rc=30 when measured with the Rc30 weight/indenter. It would read Ra=65 with the Ra weight/indenter and 15N=75 on the superficial hardness tester with the 15N weight/indenter. A table of conversions can be found in Appendix B.

APPENDIX B HARDNESS CONVERSION TABLES

APPENDIX C HARDNESS TESTING DETAILS

APPENDIX B

E 140

TABLE 6 Approximate Rockwell Hardness Conversion Numbers for Austenitic Stainless Steel Sheets

NOTE—These conversions are based on interlaboratory tests conducted on the following grades: Types 201, 202, 301, 302, 304, 304L, 305, 316, 316L, 321, and 347. Tempers ranged from annealed to extra hard for Type 301, with a smaller range of tempers for the other types. Test coupon thicknesses ranged from approximately 0.1 in. (2.5 mm) to 0.050 in. (1.27 mm).

Rockwell Hardness Number		Rockwell Superficial Hardness Number			
C Scale, 150-kgf Load, Diamond Penetrator	A Scale, 60-kgf Load, Diamond Penetrator	15-N Scale, 15-kgf Load, Superficial Diamond Penetrator	30-N Scale, 30-kgf Load, Superficial Diamond Penetrator	45-N Scale, 45-kgf Load, Superficial Diamond Penetrator	
48	74.4	84.1	66.2	52.1	
47	73.9	83.6	65.3	50.9	
46	73.4	83.1	64.5	49.8	
45	72.9	82.6	63.6	48.7	
44	72.4	82.1	62.7	47.5	
43	71.9	81.6	61.8	46.4	
42	71.4	81.0	61.0	45.2	
41	70.9	80.5	60.1	44.1	
40	70.4	80.0	59.2	43.0	
39	69.9	79.5	58.4	41.8	
38	69.3	79.0	57.5	40.7	
37	68.8	78.5	56.6	39.6	
36	68.3	78.0	55.7	38.4	
35	67.8	77.5	54.9	37.3	
34	67.3	77.0	54.0	36.1	
33	66.8	76.5	53.1	35.0	
32	66.3	75.9	52.3	33.9	
31	65.8	75.4	51.4	32.7	
30	65.3	74.9	50.5	31.6	
29	64.8	74.4	49.6	30.4	
28	64.3	73.9	48.8	29.3	
27	63.8	73.4	47.9	28.2	
26	63.3	72.9	47.0	27.0	
25	62.8	72.4	46.2	25.9	
24	62.3	71.9	45.3	24.8	
23	61.8	71.3	44.4	23.6	
22	61.3	70.8	43.5	22.5	
21	60.8	70.3	42.7	21.3	
20	60.3	69.8	41.8	20.2	

H Scale, 100-kgf Load, $\frac{1}{16}$ -in. (1.588-mm) Ball	A Scale, 60-kgf Load, Diamond Penetrator	F Scale, 60-kgf Load, $\frac{1}{16}$ -in. (1.588-mm) Ball	15-T Scale, 15-kgf Load, $\frac{1}{16}$ -in. (1.588-mm) Ball	30-T Scale, 30-kgf Load, $\frac{1}{16}$ -in. (1.588-mm) Ball	45-T Scale, 45-kgf Load, $\frac{1}{16}$ -in. (1.588-mm) Ball
100	61.5	113.9	91.5	80.4	70.2
99	60.9	113.2	91.2	79.7	69.2
98	60.3	112.5	90.8	79.0	68.2
97	59.7	111.8	90.4	78.3	67.2
96	59.1	111.1	90.1	77.7	66.1
95	58.5	110.5	89.7	77.0	65.1
94	58.0	109.8	89.3	76.3	64.1
93	57.4	109.1	88.9	75.6	63.1
92	56.8	108.4	88.6	74.9	62.1
91	56.2	107.8	88.2	74.2	61.1
90	55.6	107.1	87.8	73.5	60.1
89	55.0	106.4	87.5	72.8	59.0
88	54.5	105.7	87.1	72.1	58.0
87	53.9	105.0	86.7	71.4	57.0
86	53.3	104.4	86.4	70.7	56.0
85	52.7	103.7	86.0	70.0	55.0
84	52.1	103.0	85.6	69.3	54.0
83	51.5	102.3	85.2	68.6	52.9
82	50.9	101.7	84.9	67.9	51.9
81	50.4	101.0	84.5	67.2	50.9
80	49.8	100.3	84.1	66.5	49.9

Date: Jan 25, 1999

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To: File

From: E. B. Schwenk

Subject: **INITIAL WORK ON PINTLE ROD-RETAINING RING PROBLEM**

A) Review of Notes Taken During Pintle Rod - Retaining Ring Demonstration at 272-AW Machine Shop.

Paula Deichelborer took me to 272-AW Machine Shop to have Chet Hammack and Fred _____ show me how a retaining ring functions to hold the pintle rod (1/13/99).

Both gentlemen talked about the "old style" 304 SS (per Rev. 0 on drawing) as the "good stuff." Rev 1, 2, and 3 (on the drawing) indicated that the pintle rod material could satisfy either 304 or 304L specification. Apparently the Rev 1, 2, or 3 material wasn't as good for a given retaining ring to "hold a load" on any pintle rod.

The following information describes ring force gage tests on pintle rod specimens #1, #2, and #3 as demonstrated by Mr. Hammack.

Specimen #1. Referred to as "fresh old material." It had circumferential scratches that were claimed to have a 40 to 100 rms roughness. A retaining ring was installed. Upon manually applying an axial load (with a ring force gage) the ring broke loose at about 30-lb. It should have broken loose at about 100-lb (or more). The gentlemen indicated that the Rockwell C hardness of the rod was $R_C = 22$ (3 rdgs). [*Check to see if this included curvature correction*]. Removal of the ring appeared to "shine-up" the rod over which the ring slid off. It also appeared to smooth-up some of the circumferential scratches (must look again under a low-power microscope). According to my notes I said that when the rod was roughened (40 to 100 rms) the release load was increased slightly; this apparently was a comment by one of the gentlemen. According to my notes I wrote down that a #24 thread file (thread chaser?) was used to roughness the surface of the rod. First the rod was rotated while holding the chaser at -45° to the axis of rotation. Then its angle was changed to $+45^\circ$. This apparently made cross-hatch type of roughened surface.

Specimen #2. This was claimed to be new Rev. 0 material, original 304 (no 304L). No surface roughening was done. The average R_C was indicated to be 20.2 (avg of 3 rdgs.). Question: *Was any curvature correction added?* Rod loaded as above; load went to about 105 lb; no movement. Ring released at 45 to 48-lb.

Specimen #3. The specimen was same as # 2 except hardness was higher ($R_C = 23.5$ (apparently avg. of 3 rdgs.)). *Check on curvature correction.* No surface roughening. Load went to about 105-lb; no movement. Release load about 53-lb.

B) Pintle Rod Hardness Measurements made on Officine Galileo Machine. (1/21/99).

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Specimen #1. (Shop measurement: $R_C = 22$, near rod center)

- a) Rockwell C Hardness -150 Kg (R_C) Rockwell 15 N Hardness (HR15N)
17.6, 17.2, and 16.8. Avg: = 17.2 70.5, 71.5, and 71.2. Avg: = 71.1

b) Curvature-Corrected Hardness Levels

$$R_C = 17.2 + 6.5^{1)} (\text{est.}) = 23.7$$

$$\text{HR15N} = 71.1 + 1.0^{2)} = 72.1$$

1) Corr. From Table 6, ASTM E18-74

2) Corr. From Table 13, ASTM E 18-74.

- c) Approx Rockwell Hardness Conversion Numbers for Austenitic SS Sheets:
(Per ASTM E 140-84, Table 6)

As-Measured w curv. corr.

Curvature-Corrected & Converted HR15N:

$$R_C = 23.7$$

$$R_C \sim 24$$

Specimen #2. (Shop Measurement $R_C = 20.2$, near rod center)

- a) Rockwell C -150 Kg (R_C): Rockwell 15 N Hardness (HR15N)
17.5, 18, and 16.8. Avg. = 17.4 73.2, 74.8, 72, and 73. Avg: = 73.3

b) Curvature-Corrected Hardness Levels

$$R_C = 17.4 + 6.5 = 23.9$$

(Per Table 6, ASTM E 18-74)

$$\text{HR15N} = 73.3 + 1.0 = 74.3$$

(Per Table 13, ASTM E 18-74)

- c) Approx. Rockwell Hardness Conversion Numbers for Austenitic SS Sheets
(Per Table 6, ASTM E 140-84)

As measured w Curv. Corr:

$$R_C = 23.9$$

Curvature-Corrected & Converted HR15N: $R_C = 29$

Note: This larger difference between R_C and converted HR15N indicates a harder surface for #2.

Specimen #3. ($R_C = 23.5$ near rod center).

- a) Rockwell C -150 Kg (R_C): Rockwell 15 N Hardness (HR15N)
19.2, 18.3, and 19.0. Avg: = 18.8 73.2, 72.2, and 72.0 Avg: = 72.5

b) Curvature-Corrected Hardness Levels

$$R_C = 18.8 + 6.5 = 25.3$$

(Per Table 6 ASTM E 18-74)

$$HR15N = 72.5 + 1.0 = 73.5$$

(Per Table 13, ASTM E 18-74)

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c) Approx. Rockwell Hardness Conversion Numbers for Austenitic SS Sheets

As-Measured w Curv. Corr: $R_C = 25.3$
Curvature-corrected & Converted HR15N: $R_C = 27$

C) Pintle Rod Diameter Measurements

Diameter measurements were made on Pintle Rods # 1, 2, and 3 by EBS using a vernier caliper. The measurements were generally orthogonal to each other and made either near the pintle end or near the opposite end.

(#1)

Dia. = 0.187 and 0.186 near opp. End.
Dia. = 0.1865 and 0.186 near pintle end.

(#2)

Dia. = 0.187 and 0.1855 -in. (near opp end)
Dia. = 0.186 and 0.186-in. near pintle end.

(#3)

Dia. = 0.186 and 0.185 near opp. End.
Dia. = 0.186 and 0.186 near Pintle end.

D) Retaining Ring Dimension Measurements

Six retaining rings were dimension-measured by EBS with a vernier caliper. Three of the rings had been removed from Pintel Rods 1-3, but were not correlated. That is, the # 1, #2, and #3 rings do not necessarily correlate with Pintle rods #1-3.

Retaining ring #4, 5, and 6 are virgin and were obtained from Paul Deichelborer; Paul apparently obtained about a dozen of them from the 272-AW Shop. EBS measured the OD, ID, web thickness (thickness away from ID-protruding lip), and lip height of all six rings. The lip height was hard to measure for the used rings #1-3, as the ring removal process caused them to warp (bend out-of- plane).

Ring. No.	<u>D_{Max}</u>	<u>D_{Min}</u>	<u>Web - t</u>	<u>Lip Height</u>	<u>Lip Height in Warp Trough</u>
1	0.370	0.184	0.012	0.040	0.040
	0.375	0.185	0.012	0.052	
			0.011		
2	0.373	0.1835	0.012	0.041	0.041
	0.373	0.184	0.0115	0.044	
			0.011		

3	0.3735	0.1845	0.012	0.050	0.040
	0.3735	0.185	0.012	0.040	
			0.011		
4	0.375	0.173	0.012	0.0275	--
	0.374	0.174	0.012	0.0270	--
			0.012		
5	0.375	0.172	0.0115	0.028	--
	0.375	0.172	0.0115	0.028	--
			0.011		
6	0.375	0.173	0.012	0.027	--
	0.375	0.173	0.0118	0.029	--
			0.012		

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E) Retaining Ring Hardness Measurements

Because the rings are so thin (about 0.012-in.) these initial hardness measurements are suspect but are probably good in a relative sense. The hardness measurements on rings #1-3 are more suspect because they were warped. The 1/4-in (?) dia. anvil would not allow a given portion of the ring to lie flat. Thus some hardness numbers are too low as can be seen. Initially Mr. Sells (Advance Tech. Svs) and I conducted Rockwell A measurements on # 4 - #6 rings but found that the reverse-side indent was most noticeable. We then went to the HR15N system and found that the backside-mark still appeared but was smaller. Thus, the HR15N measurements are speculated to be better (but still relative).

<u>Ring No.</u>	<u>HR15N</u>	<u>Comment</u>
#1	47	Used 1/4-in. dia. anvil on warped #1-3 rings. Ring prob. not flat
	6	
	64.8	
	76 (R _C 32)*	
	77 (R _C 34)	
#2	47	
	53.5	
	59	
#3	54	meas. prob. made in warp
	58	
	17	
	46	
#4	65.2	Note: we used a flat anvil for rings #4-6.
	62.5	
#5	53.5	
	49	
	51.5	
#6	47	
	48	
	48.5

*HR15N conversion to R_C taken from ASTM E 140-84. Note that a HR15N measurement of about 70 is the lowest value that can be converted to an $R_C = 20$. Values less than 70 don't exist as they would be equivalent to R_C values < 20 . Thus, one must make HR15T (1/16-in. dia. ball) indenter measurements in order to convert the HR15T measurements to Rockwell B values.

Note: There is a fair amount of scatter in the hardness data. Some may be related to the backside-denting but part of it is probably real. I must try the 1/16-in. dia. ball (15-T) superficial indenter.

Date: Jan 29, 1999

To: File

From: E. B. Schwenk

Subject: 2nd CUT AT PINTEL-RETAINING RING HARDNESS EVALUATION

On 1/27 and 1/28 I conducted additional hardness measurements on the retaining rings (1/27) then on the Pintel rods (1/28). Here's the data.

1) Calibration

I put in the C-Brale indenter (150-Kg) and checked the R_C readings on the 26.5 ± 1 and the 44.4 ± 1 hardness blocks both on the 2-in. dia. flat anvil. They are (after throwing away the first rdg):

$R_C = 26.5$ Block
27.5 & 26.0 (OK)

$R_C = 44.4$ Block
43.5 & 44.5 (OK)

Next I put the N-Brale indenter (15 Kg) in the Officine Galileo hardness machine and made hardness impressions in the $R_C = 26.5$ block. The readings are:

$R_C = 26.5$ Block
72, 71.8, 71.5 (OK) [Note: these values are approximately equivalent to
 $R_C = 24$, from Hardness Conversion Table]

**2) Repeat Retaining Ring Hardness Measurements (Made with New, Small
<1/4-in. dia. Anvil)**

Ring No.	HR15N	Avg.	R_C Conversion	Comment
1) (warped)	69 66 63 56.5 65	66	18?	Some of these indents may be showing up (faintly) on the back side. Some indents appear slightly non-round on the indenter side. Probably due to warp in #1 ring.
2) (warped)	66.3 75 73.5 74.5	72.2	25	Marks do not appear to show-through on back side.
3) (warped)	69 71.5 71.5	70.7	22	No show-through.
4)	73.9 74.1 74.5	74.2	29	Impressions do not show-through on opposite side.

5)	73.0 73.9 73.0	73.3	27.7	Impressions do not show-through.	32 of 64 RPP-5114 Rev 0
6)	73.2 72.5 78.8 71.0	73.9	28	No show-through.	

2) Repeat hardness Measurements on Pintel Rods (1/28/99)

I re-calibrated the Galileo machine on the R_C 26.5 and 44.4 blocks. OK.
Next I exchanged the flat (2-in.) anvil for our V-block anvil.

<u>Pintel Rod</u> <u>No.</u>	<u>Hardness</u> (R_C -150-Kg.)	<u>Avg. R_C +</u> <u>Curv. Corr.</u>	<u>Curv. Corr. R_C</u>	<u>Comment</u>
1	18.1, 19.8, 19.0, 18.5	18.9 + 6.5	25.4	Made these measurements about 90° rotated from first set of measurements.
	20		---	Rotated back 90°
2	21, 22, 20.8, 19.5	20.8 + 6.5	27.8	Made these measurements about 90° rotated from first set of measurements.
	20		---	Rotated back about 90°.
3	22, 23, 22,	22.3 + 6.5	28.8	Rotated about 45° from initial measurements.
	21		---	Rotated back about 45°.

Now exchanging R_C Brale indenter for HR15N Brale indenter. Using same V-block anvil. Recalibrated with $R_C = 26.5$ Block. HR15N measurements = 71.0, 71.0, 71.0 (OK).

<u>Pintel Rod</u> <u>No.</u>	<u>HR15N</u>	<u>Avg. 15N +</u> <u>Curv. Corr^{a)}</u>	<u>R_C b)(Equiv.)</u>	<u>Comment</u>
1	71.5, 72.5, 60.5, 71	72.7 + 1 =	73.7 28	Low reading due to not seating properly in V-block. These readings made close to just-made R measurements made above.
	71, 70.3, 70.5	70.6	-- --	Rotated back to earliest R _c measurements.
2	73.5, 72.8, 74.8	73.7 + 1 =	74.7 30	Readings made close to recent R _C measurements.
	73.4, 73.1	73.3	-- --	Rdgs made close to 1st set of R _C measurements.
3	73, 72, 72	72.3 + 1 =	73.3 27	Rdgs made near recent set of R _C measurements.
	77.5, 73	75.3	-- --	Rotated back to 1 st set of measurements.

a) Curvature corrections taken from Table 18 of ASTM E 18-74.

b) Hardness conversion taken from Table 6, ASTM E 140-84.

Date: Feb. 3, 1999

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To: File

From: E. B. Schwenk

Subject: **WORK HARDENING of 304L and 304 SS and CONVERSION to R_C**

The following Table shows how much both Type 304L and Type 304 SS strongly work harden (i.e., rapidly gain strength with increasing cold work). Further, the data also show and that there are some nominal differences in strength behavior, particularly in the lower cold work ranges (i.e., 0 to 5%).

Table 1. Comparison of the Work Hardening Behavior of Type 304L and Type 304 SS.

<u>Type 304L SS^{a)}</u>			<u>Type 304 SS^{a)}</u>				
% Cold Work	Y.S. (Ksi)	U.T.S. (Ksi)	% Cold Work	Y.S. (Ksi)	U.T.S. (Ksi)	Vickers ^{b)} Hardness	R _C ^{c)} Conversion
0	33	81	0	35	85	155	-
5	61	95	5	50	90	200	-
10	73	106	10	70	98	225	< 20?
15	80	112	15	82	105	260	24
20	88	122	20	98	112	280	27
25	107	130	25	107	122	300	30
30	120	138	30	120	133	315	31.5
35	130	155	35	127	139	--	
40	138	153	40	135	147	335	34
50	152	169	50	146	159	345	35
60	--	--	60	151	167	360	37

a) From Handbook of Stainless Steel, by D. Peckner and I. Bernstein, McGraw-Hill Book Co., New York, 1977, pp 20-29, Fig. 27.

b) From ASM metals Handbook, Vol. 4, Forming, 8th Edition, 1969, Metals Park, Ohio.

c) Approximate Conversion (based on non-austenitic steel) from ASM Metals handbook, Vol. 8, Mechanical Testing, 9th Edition, pp 84=89, 1985, Metals Park, Ohio.

All the HR15N hardness measurements for the three rods and 12 rings are shown in Table 2, below.

Date: Feb. 3, 1999

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To: File

From: E. B. Schwenk

Subject: 3rd CUT AT RETAINING RING HARDNESS EVALUATION

On 2/3/99 I conducted HR15N (Brale Indentor) measurements on six (6) additional rings (numbered 7 to 12). These were from the original batch that P. Deichelborer had gotten for me, apparently from the 272-AW shop.

1) Calibration

I used both the $R_C = 34.9 \pm 1$ block and the $R_C = 26.5 \pm 1$ block for calibrating the HR15N scale.

The measurements on the 34.9 block were:

76.5, 76.9, and 76

The measurements on the 26.5 block were:

72, 71, 71.

2) New Retaining Ring Hardness (HR15N) Measurements

<u>Ring. No.</u>	<u>HR15N</u>	<u>Avg.</u>	<u>R_C Conversion</u>	<u>Comment</u>
7)	76.3 76 75.8	76	32	
8)	72.5 73.5 73	73	26	
9)	72.5 74.5 73	73.3	27	
10)	73 79 73	75	30	
11)	75 76.5 77	76.2	32.5	
12)	74 74.5 74.5	74.3	29	

Table 2 Grand Average of HRN15 Hardness Values – Converted to Rockwell 36 of 64
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	<u>Pintel Rods (#1, 2, & 3)^(a)</u>	<u>Retaining Rings (#1-12)^(b)</u>
Max.	30	32.5
Avg.	28	27.2
Min.	24	18

- a) Total No. of measurements: 22
- b) Total No. of measurements: 38.
- c) Note also that rings 1, 2, and 3 had been warped as a result of being removed from Rod 1, 2, & 3; there is no correlation between PR No. and Ring. No. for the first three rings.

RESULTS

The results shown in Table 2 indicate that the hardness values of the rods and rings are similar but that the rings have a wider range of hardness values. This latter point may be the reason why some rings do not 'bite' into a given rod. For example, a R_C 18 interference fit ring will not likely plastically indent a R_C 30 rod. Correspondingly, a R_C 32.5 ring might be able to indent all of the pintel rods (assuming none have a hardness > R_C 30).

It should be noted that all the hardness measurements made on the rings were taken on their flat annular surfaces. Furthermore, these 'flat' hardness measurements probably do not accurately reflect the hardness of the more highly-worked curved portion of the ring. The latter is the part of the ring that digs into its mating rod. It is likely however, that the curved region does not have a significantly higher hardness level than its nearby flat region. This effect can be noted in Table 1 above. The R_C 32.5 value for the flat portion of a given ring corresponds to an approximate cold work level of about 35%. Note that as cold work increases to 40% and more, that the hardness level does not increase as fast as it did for lower cold-work levels.

No superficial hardness measurements could be made in the 'biting' portion of the ring because of its extreme curvature. It is possible to obtain microhardness measurements in this high curvature region but would require metallurgically mounting, sanding, and polishing each ring. This would be costly; in addition, the hardness measurements would be more costly as the time to make the measurements is increased in comparison to the superficial hardness tester that was used.

RECOMMENDATIONS

The present 'fix' of reducing the hardness of the pintle rods (by a thermal softening treatment) appears to be the most economic way of improving the load-carrying capability of a given ring-rod combination. Successful load-release tests on a number of stress-relieved rods would appear to provide you with a technical basis for ameliorating the problem.

It is recommended that HR15N (superficial) hardness measurements be made on statistically significant number of rods and rings that have been shown to meet your load-release needs. My assumption is that the hardness range for the rings will be less than the range for the rods. If this is the case, then as additional rods or additional rings are purchased, they could be hardness-checked as a quality assurance measure. If their hardness ranges are not satisfactory, and their load-release values are also unsatisfactory, then we should have a technical basis for again applying a thermal treatment to the rods assuming that their surface hardness (or overall hardness) is too high. Or, correspondingly, just reject the components that don't meet the desired hardness ranges.

Date: February 4, 1999

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To: J. L. Smalley

cc. P. R. Deichelborer

From: E. B. Schwenk

Subject: **RESULTS OF PINTLE-ROD AND RETAINING RING
HARDNESS EVALUATION [DRAFT]**

INTRODUCTION

Three pintle rods and 12 retaining rings were hardness-evaluated to see if superficial hardness measurements might provide an explanation of why some previous rod-ring combinations displayed a reduced release load. Hardness measurements made included standard Rockwell 'C' and superficial hardness (HR15N) all made on an Officine Galileo Hardness machine located at building 306 E. Only the HR15N measurements were used for assessing possible hardness disparities between rod and ring. Standard Rockwell C measurements tended to parallel the HR15N measurements but provided only a relative measure of hardness.

These HR15N measurements, on the subject items, showed trends that may explain why premature release occurred.

RESULTS

HR15N^(a) hardness measurements were made on three pintle rods and 12 retaining rings. Three of the retaining rings had each been pulled off their respective three pintle rods. No correlation was maintained between rod and ring. That is, ring #1 may have come off rod #1, 2, or 3. This however, did not negate the results of the hardness tests.

Twenty-two HR15N hardness measurements were made on the three pintle rods and 38 measurements made on the 12 retaining rings. The results, converted to Rockwell C (R_C) are shown in Table 1.

Table 1 Grand Average of HRN15 Hardness Values – Converted to Rockwell C

	<u>Pintle Rods (#1, 2, & 3)</u>	<u>Retaining Rings (#1-12)</u>
Max.	30	32.5
Avg.	28	27.2
Min.	24	18

(a) Superficial hardness measurements made with a 15-Kg. load and a diamond or 'N-Brale' indenter.

The results shown in Table 1 indicate that the hardness values of the rods and rings are similar but that the rings have a wider range of hardness values and a higher maximum value. This latter point may be the reason why some rings do not 'bite' into a given rod. For example, a R_C 18 interference fit ring will not likely plastically indent a R_C 30 rod. Correspondingly, a R_C 32.5 ring might be able to indent all of the pintle rods (assuming none have a hardness $> R_C$ 30).

It should be noted that all the hardness measurements made on the rings were taken only on their flat annular surfaces. Furthermore, these 'flat' hardness measurements probably do not accurately reflect the hardness of the more highly-worked curved portion of the ring. The latter is the part of the ring that digs into its mating rod. However, it is likely that the curved region does not have a significantly higher hardness level than its nearby flat region. This effect can be noted in the appended Table 2 below. The R_C 32.5 value for the flat portion of a given ring corresponds to an approximate cold work level of about 35%. Note that as cold work increases to 40% and more, that the hardness level does not increase as fast as it did for lower cold-work levels.

Not knowing the actual hardness of the 'biting lip' is probably not critical because we do not know how much higher the lip hardness has to be, relative to the rod surface hardness, to provide a satisfactory release load. Thermal stress relief treatments have already been done on some of the remaining pintle rods and have likely been tested for their release loads. If the release loads are satisfactory, it is recommended that additional superficial hardness measurements be made on these successful rod-ring combinations to see what their hardness 'windows' looks like. Most likely, they will display less overlap. If this is the case, then 'quality assurance' superficial hardness measurements on given batches of rods and rings may provide a means for minimizing the premature release problem.

SUMMARY

An undesirable overlap in the hardness 'windows' for the rods and rings may have contributed to the problem of low release loads. Reducing the hardness range for the pintle rods may be a way for managing the low release load problem.

RECOMMENDATIONS

If a reduction in the hardness range for the pintle rods does solve the low release load problem, then superficial hardness measurements on successful rod-ring combinations may provide a means for either acceptance/rejection testing of new products, or a guide for applying thermal stress relief treatments to already available products.

No superficial hardness measurements could be made in the 'biting' portion of the ring because of its extreme curvature. It is possible to obtain microhardness measurements in this high curvature region but this would require metallurgically mounting, sanding, and polishing each ring. This would be costly; in addition, the hardness measurements would be more costly as the time to make the measurements is increased in comparison to the superficial hardness tester that was used.

BACKGROUND INFORMATION

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The following Table shows how much both Type 304L and Type 304 SS strongly work harden (i.e., rapidly gain strength with increasing cold work). Further, the data also show and that there are some nominal differences in strength behavior between the two alloys, particularly in the lower cold work ranges (i.e., 0 to 5%).

Table 2. Comparison of the Work Hardening Behavior of Type 304L and Type 304 SS.

<u>Type 304L SS^{a)}</u>			<u>Type 304 SS^{a)}</u>				
% Cold Work	Y.S. (Ksi)	U.T.S. (Ksi)	% Cold Work	Y.S. (Ksi)	U.T.S. (Ksi)	Vickers ^{b)} Hardness	R _C ^{c)} Conversion
0	33	81	0	35	85	155	-
5	61	95	5	50	90	200	-
10	73	106	10	70	98	225	< 20?
15	80	112	15	82	105	260	24
20	88	122	20	98	112	280	27
25	107	130	25	107	122	300	30
30	120	138	30	120	133	315	31.5
35	130	155	35	127	139	--	
40	138	153	40	135	147	335	34
50	152	169	50	146	159	345	35
60	--	--	60	151	167	360	37

a) From Handbook of Stainless Steel, by D. Peckner and I. Bernstein, McGraw-Hill Book Co., New York, 1977, pp 20-29, Fig. 27.

b) From ASM metals Handbook, Vol. 4, Forming, 8th Edition, 1969, Metals Park, Ohio.

c) Approximate Conversion (based on non-austenitic steel) from ASM Metals handbook, Vol. 8, Mechanical Testing, 9th Edition, pp 84-89, 1985, Metals Park, Ohio.

Date: Feb. 10, 1999

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To: File

From: E. B. Schwenk

Subject: 5th CUT AT EVALUATING PINTLE RODS

On Feb. 8 and 9, 1999 I looked at a number of heat-treated pintle rods using a low-power stereo microscope located in the high-bay region of 306 E bldg. The rods ranged in length from about 5 to 9-in. Here is a list of my observations. The designation A), B), etc. is what I used to separate one set of rods from another.

A) Knurled Rods (1 end) - 5 notches ground into each rod. (In plastic ziplok bag)

I designated one rod as 5N-1, the other 5N-2. The attached Beaver Heat Treat card said: 1/12/99. P.O. No. P09-002, R_C 16-17. The inspector was Dan; the apparent exposure temperature was 1150 (I presume this means °F). No exposure time noted. Both rods have a light-blue tinge. Each is relatively smooth (except for knurling and retaining ring areas) and has an estimated finish of about 32 microinch more or less.

Specimen 5N-1 had two (2) hardness marks (impressions) about 1-3/4-in. from the knurled end and another 2 marks about 3/8-in. from the same knurled end. The rod also had a 'white' 1 written on it.

Specimen 5N-2 has 3 impressions about 3/8-in. from the knurled end and another 2 about 3/4-in. from the same end.

B) Two Rods each with 4-notches ground into each rod (In plastic ziplok bag)

I designated one rod as 4N-1 the other as 4N-2. Both rods had a thin, mottled oxide layer (probably angstroms thick). The Beaver Heat treat data card indicated P09-0002, 1/12/99 with a R_C of 22. Inspected by Dan and 1050 (probably for °F). No time noted.

Specimen 4N-1 has a 'white' 1 on it. The end opposite the 4-notches was apparently machine-wire brushed (circumferentially). It also shows a 360° depression about 1/4-in. from the non-notched end. Apparently the ring grabbed securely. The opposite end (oxidized) may have had a ring put on it. It did not leave a depression as deep as the other. I did not see any hardness indents.

Specimen 4N-2 has a 'white' 2 on it. About 1/2 of this rod was machine wire-brushed. Seven hardness impressions range from about 1-in. to 1 and 3/4-in. from the unnotched end (also in the machine-brushed area). Three of the impressions appear to have been made before wire brushing (they appear fuzzy) [one farthest from the end and two about intermediate from the same], the remaining four made after brushing. A ring was

apparently put on the unnotched end but appears to have left only 4 depressions, each separated about 90°.

C) Two Rods each with 6 notches ground into them (In plastic ziplok bag)

Both of these rods have a light yellow tinge. The Beaver Heat Treat card says PO9-0002, date 1/12/99. R_C was 13. Inspected by Dan and 1250 (presumably °F). No exposure time noted.

Specimen 6N-1 is finely knurled at one end and has a 'white' line in its center. The end with the notches is opposite the knurled end. There are 6 hardness impressions. The 2 indents nearest the middle of the specimen (farthest from knurled end) appears to have been made after some circumferential abrasion. The remaining 4 indents (closer to the knurled end) appear to have been made without any prior circumferential abrasion or wire brushing. The knurled end (about 1/2-in. long) appears to have had a ring placed on it then removed; it was placed about 0.4-in. in from the knurled end.

Specimen 6N-2 has more coarse knurling on both of its ends. The knurled end, opposite the 6 notches appears to have had a retaining ring placed about 0.4-in. on, from the end of the rod, then removed. Five hardness indents were seen from about 0.2-in. to about 0.8-in. from the same ringed and knurled end.

D) Two Rods each with 7 Notches Ground into them (In plastic ziplok bag)

Both rods have a light, mottled oxide layer (probably angstroms thick) much like those noted in B) above. Each had about a 1-in. long circumferentially machine-brushed area closest to their unnotched ends. The Beaver Heat treat data card indicated PO9-0002, Date 1/13/99. They were inspected by 'L' and had an R_C of 20-21. 1100 and 3-hrs were also noted (presumably temperature and time of exposure).

Specimen 7N-1 had 6 hardness impressions in its machine-brushed region. Two were fuzzy indicating that they were probably made before brushing (one additional was in the oxide area). Two hardness impressions were apparently made after brushing. One additional indent, near the latter two was apparently made after its region was further abraded, probably with a file. One ring was apparently put on the unnotched end. Its 'depression' was somewhat serpentine indicating that it was warped upon its initial attachment and was removed while in its warped state. The depression did, however, cover the entire 360° of the rod.

Specimen 7N-2 has 8 hardness impressions: 4 apparently made before wire brushing and 4 afterwards. All 8 are nearest the unnotched end. Two of the four, made afterward, were in the brushed area; the other two appear to have been made after further filing of the machine-brushed region. A ring appears to have been put on the unnotched end and then removed. It did not leave a significant depression but did scratch off much of the very thin oxide layer.

E) Five Rods, light Brown in Color, no notches. (Secured with Beaver tag and tape)

Beaver data: Date 1/22/99, no P.O. no. noted. 1100 for 3 hrs. Inspected by 'N'? No hardness numbers noted. Also, no apparent hardness rdgs were made. I designated these 5 rods as LB

LB-1. One end (near shear pin hole) appears "chased" with a thread chaser. Deep depression due to biting ring near pin hole end. Depression was serpentine indicating a warping of the ring. The depression showed 360° around the circumference.

LB-2. The end near the pin hole appears to have had a ring put on and removed. Little circumferential bite noted. Ring only lightly scratched the rod during removal.

LB-3. Ditto LB-2 except it has a deeper depression apparently due to a 'biting' ring (360°). Ring mark is also serpentine indicating that it was warped during its application.

LB-4. Like LB-1. Ring apparently put on and removed. Only left a partial bite over majority of circumference.

LB-5. Some light thread chasing near pin hole end. Ring put on and pulled off. It left a bite over 360°. About ½ (180°) was fairly deep, the other ½ light.

F) Five Rods Light Blue in Color, no notches, no pin holes. (Secured in nylon : sock-wrap)

Beaver Data: PO9-0002; Date: 1/15/99 ;SR 1100 3 hrs. Inspected by 'L'?
I designated these rods "B". No hardness impressions noted on all of the rods.

B-1. End opposite vibroetched 'B-1' appeared to have had two different rings attached. One shows a 4-pronged attachment with dig-in marks at 90° intervals about ¾-in. from end. A standard ring appeared to have been put on the rod to a point about ½-in. from the end. This ring left some light markings (depressions) and had about a 200° + coverage circumferentially around the rod. I can't tell which ring was put on first as the 4-pronged ring dug deeply into the rod obscuring the previous(or following) standard ring markings.

B-2. This rod had rings attached on both ends. Vibro-etched end has 4 deep marks indicating a 4-pronged ring had been attached asnd removed. The opposite end appears to have had two rings attached and removed. One ring dug in at the typical 90° positions; the other ring left a serpentine 360° depression and only scraped a small portion of the rod when being removed.

B-3. This rod had rings attached on both ends. The vibro-etched end had a 4-pronged ring attached, which dug in deep in two of its four locations. The opposite end had a standard ring attached. It dug in lightly over about 180° and was slightly serpentine in its shape.

B-4. This rod had only one ring attached on end opposite vibro-etch mark. It was a standard ring; it dug in and left a serpentine depression over the 360° circumference.

B-5. This rod too had only one ring attached and removed. It appears to have been a standard ring; it dug in lightly over about 180° of the circumference and was slightly serpentine.

Date: Feb. 22, 1999

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RPP-5114 Rev 0

To: File

From: E. B. Schwenk

Subject: 6th CUT AT EVALUATING HARDNESS OF PINTLE RODS

On Feb. 11, 12, and 19 I conducted superficial hardness measurements (Rockwell HR15N, using a 15 Kg weight) on 15 pintle rods. They had generally been heat treated (stress-relief annealed) various amounts. On virtually all of the specimens I also made low-power optical observations both before and after HR15N impressions were made. This was done to ensure that the hardness impressions' shape was satisfactory (generally round) and to determine where the impressions were located.

A) Knurled Rods (1 end) - 5 notches ground into each rod. (1150° F, R_C 16-17)

Used R_C test block 26.5 ± 1 for calibration. Hardness (HR15N) measurements were 72.2 and 72. These compare well with previous calibration measurements.

1) Specimen 5N-1. I made hardness indents near "vibroetched" 5N-1.

Pintle Rod No.	Hardness	Comment
5N-1	65	Bad rdg; tape on rod
	69.5	Ok
	70.9	Ok
	51	Bad rdg; some tape on rod.
	71	

Avg. hardness (HR15N) = $70.5 + 1$ (curvature corr.) = 71.5 (= R_C 23+)

2) Specimen 5N-2. I made hardness indents near "vibroetched" 5N-2.

Pintle Rod. No.	Hardness (HR15N)	Comment
5N-2	64	Bad rdg.
	67.3	Ok
	70	Ok
	67	Ok
	69	Ok

Avg. hardness (HR15N) = $68.3 + 1$ (curv. Corr) = 69.3 (=R_C ~19.5)

Note: I must go back and get hardness measurements in knurled ends.

B) Two Rods each with 4-Notches Ground into Each Rod (1050° F, R_C 22))1) Specimen 4N-1.

Pintle Rod No.	Hardness (HR15N)	Comment
4N-1	71	Machine-brushed end
	72	Ditto above
	75	Ditto
	71	Lightly oxidized end (around vibro-etch no.)
	72.5	Ditto above
	72	

Avg. HR15N (machine-brushed end) = $72.7 + 1$ (curv. corr.) = 73.7 (= R_C 27.5)
[Should I get more measurements here?]

Avg. HR15N (oxidized end) = $71.8 + 1$ (curv. corr) = 72.8 (= R_C 25.5)

Pintle Rod No.	Hardness (HR15N)	Comment
4N-1	74	Bright end (machine-brushed), between end & ring indent.
	72	Ditto above
	73	Ditto
	78	Opposite end (lightly oxidized) between ring mark and end of rod.
	78.5	Ditto above
	74	Ditto

Avg. HR15N (bright end) = $73 + 1$ (curv. corr.) = 74 (~ R_C 28)

Avg. HR15N (mottled end) = $76.8 + 1$ (curv. corr.) = 77.8 (~ R_C 35)

2) Specimen 4N-2

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Pintle Rod No.	HR15N	Comment
4N-2	74.2	These indents made near previous Beaver hardness indents (machine-brushed area). EBS indents look smaller than Beavers'; I suspect they used 30 Kg (or more).
	74	Ditto above
	72	Ditto
	72	Lightly oxidized end, near vibroetch mark 4N-2.
	71	Ditto above
	70	Ditto
	71	Machine-brushed area between end & ring mark. Note that ring appears to have indented heavily in 3 areas but still looks like it was a std. ring.
	74	Ditto above.

Avg. HR15N (machine-brushed end) = $73.4 + 1$ (curv. corr.) = 74.4 (R_C 29)

Avg. HR15N (machine-brushed end between end & ring mark) = $72.5 + 1$
= 73.5 (R_C 27)

Avg. HR15N (lightly oxidized end) = $71 + 1$ (curv. corr.) = 72 (R_C 24)

C) Two Rods each with 6 Notches Ground into Them (1250° F, R_C 13))

1) Specimen 6N-1 (One knurled end, one smooth end)

Pintle Rod No.	HR15N	Comment
6N-1	67	Near knurled end; also near hardness indents made by Beaver (closest to end)
	68	Ditto above.
	67	Further away from knurled end near 2 nd set Beaver marks.
	69	Ditto above
	67	Further away from knurled end but outside of filed area.
	58.5	Inside filed area.
	63	Also in filed area.
	60	Ditto above
	64	Ditto
	72	In knurled region, clean end (unabraded by ring); indents made in 'valley' and into 'land.'

	74	Ditto above.
	40.5	Looks like indent slid off a 'land.'
	74	Mainly in valley
6N-1	74	In ring-abraded area in knurled region. Indent centered in groove but mark spreads into two lands.
	73	
	72.5	Substantially in land but some groove.
		Note: while hardness measurement differences between the knurled-clean and knurled-ring-abraded are not large, the asperities are "knocked-off" in the ring-abraded area. This clipping of the asperities would be expected to affect the load required to remove a 2 nd retaining ring. In addition, the clipped asperity regions might have a slight increase in hardness over the knurled region.

6N-1

Avg. HR15N in smooth area near knurled end = $67.8 + 1$ (curv. corr.) =
68.8 (~ R_C 19?)

Avg. HR15N in smooth, filed area = $61.4 + 1$ (curv. corr.) = 62.4 (R_C <17 ?)

Avg. HR15N in knurled region, non ring-abraded = $73.3 + 1$ (curv. corr.) =
= 74.3 (R_C 29)

Avg. HR15N in knurled & ring-abraded region = $73.2 + 1$ (curv. corr.) =
= 74.1 (R_C 28.5)

2) Specimen 6N-2 (Knurled at both ends, non-notched end had ring attached)

Pintle Rod No.	HR15N	Comment
6N-2	62	Indents made near old indents in smooth region; also near knurled end (opposite other knurled end with 6 notches).
	34	Ditto above; bad rdg.
	68.5	Ok
	64	Ok
	67	Ok
6N-2	64	Indents in knurled-only region (w 6 notches). In groove, spilled out into 2 lands.
	70.5	Indent > 50% in a land.
	59	At corner, biased by slippage toward 2 valleys (bad rdg).
	67	Mainly in land but bulged into nearby valley. These 4 rdgs are likely biased but indicate that the knurled region is harder than the smooth region.
6N-2	69	Indents here made in knurled end. Could not find 1 st indent among the knurls.
	66	Both this rdg and above rdg may have been centered in a valley – hard to see.
	75	Could not find this indent and one below; must have been in valleys.
	72	
	Nil	Ring-abraded portion of knurled region. No reading here; apparently slid off a land.
	79	In valley

Avg HR15N in smooth area (near unnotched end) = $65.4 + 1$ (curv. corr.) =
= 66.4 ($R_C < 17?$)

Avg HR15N in knurled-only end (w 6 notches) = biased value. Actual hardness probably higher due to knurl-work hardening. No accurate measure was possible.

Avg. HR15N in knurled-only end. Number may reflect both lands and grooves.
= $70.5 + 1 = 71.5$ ($R_C 22+$)

Avg. HR15N in knurled end only + ring-abraded. Numbers hard to get.
One was = $79 + 1 = 80$ ($R_C 40$)

D) Two Rods with 7 Notches Ground into them No knurling either end (1100° F for 3-hrs, R_C 20-21)

1) Specimen 7N-1

Pintle Rod No.	HRN1	Comment
	5	
7N-1	78	Indent made near end Beaver indent (unnotched end) also in machine-abraded region.
	72	Made near 2 nd Beaver indent.
	71.5	Made near 3 rd indent in filed area.
	70	Made near 1 st Beaver indent.
	72	Ditto above.(all above in machine-abraded area).
	70	Made in lightly oxidized area near 7-notch end.
	70	Ditto above
	64.5	Indenter looks crooked vis-à-vis V-block.
	20	Bad rdg (off of diametral line)
	68	These last three indents also look distorted. Apparently end of specimen is bent precluding accurate hardness measurements. Note that these three measurements were made in region where ring was removed.

Avg. HR15N in machine-abraded area = $72.7 + 1$ (curv. corr.) = 73.7 (R_C 27.5)

Avg. HR15N in lightly oxidized area = $70 + m 1$ (curv. corr.) = 71 (R_C 22.5)

Avg. HR15N in ring-abraded area could not be made due to distortion in rod end.

Note: I apparently did not do hardness indents on specimen 7N-2.

2) Specimen 7N-2

E) Five brown-tint Rods (No knurling either end but does have thread-chasing) (1100° F for 3-hrs)

Only three rods were hardness-evaluated.

1) Specimen LB-1

Pintle Rod No.	HR15N	Comment	51 of 64 RPP-5114 Rev 0
LB-1	69	Near LB-1 vibroetch end. (smooth surface)	
	70	Ditto above.	
	68.5	Ring-abraded + thread-chased end (opposite to LB-1 Vibroetch)	
	67	Ditto above	
	80	Non-ring-abraded but thread-chased.	
	66.5	Ditto above.	

Avg. HR15N for smooth end $69.5 + 1$ (curv. corr.) = 70.5 (R_C 21.5)

Avg. HR15N for ring-abraded and thread-chased = $67.8 + 1$ (curv. corr.) = 68.8 ($R_C < 20$).

Avg. HR15N for non-ring abraded but thread-chased = unclear, probably due to lands and grooves.

2) Specimen LB-5

Pintle Rod LB-5	HR15N	Comment
	69	Smooth surface near LB-5 vibroetch.
	71	Ditto above
	72	Ditto
	65.5	In thread-abraded and ring-abraded area.
	68	Ditto above.
	70	Look at rod to determine location.
	69	

Avg. HR15N for smooth surface = $70.7 + 1$ (curv. corr) = 71.7 (R_C 23.7)

Avg. HR15N in thread-abraded and ring-abraded appear similar to smooth area.

F) Five Rods Light Blue in Color, no notches, no pin holes. (11w9f - 3hrs)

Vibro-etched as B1, B2, B3, B4, B5.

1) Specimen B-1

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Pintle Rod No.	HR15N	Comment
B-1	73	Made on smooth surface near B-1 vibroetch mark.
	68	Ditto above.
	68	Ditto
	68	Ditto
	66	Now in ring-abraded area but not quadrifoil area (all close to opposite end of rod).
	68	Ditto above
	68.5	Ditto

Avg HR15N in smooth surface = $69.3 + 1$ (curv. corr.) = 70.3 (R_C 21)

Avg HR15N in ring-abraded area = $67.5 + 1$ (curv. corr.) = 68.5 (R_C <19?)

2) Specimen B-2

Pintle Rod No.	HR15N	Comment
B-2	69	Measurements made near vibroetch B-2 mark
	68	
	70	

Avg. HR15N = $69 + 1$ curv. corr. = 70 (R_C 20.5)

G) D. Graves Specimens (Heat-treated to red-heat)

1) Specimen G-1

Pintle Rod No.	HR15N	Comment
G-1	68	Hardness measurements made nea vibroetched end (clean)
	72	Ditto above
	70	Ditto
	51.5	Hardness measurements made near darkened end
	52	
	50	

Avg. HR15N for clean end = $70 + 1$ (curv. corr.) = 71 (R_C 20.5)

Avg HR15N for darkened end = $51.2 + 1$ (curv. corr.) = 52.2 (R_C <15?)

2) Specimen G-2

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Pintle Rod No.	HR15N	Comment
	70	Measurements made near clean (vibroetched) end.
	74	Ditto above.
	69	Ditto
	54	Measurements made toward middle of dark area
	50	Ditto above.
	57	Ditto

Avg. HR15 N for clean end = $71 + 1$ (curv. corr.) = 72 (R_C 24)

Avg. HR215N for dark end = $53.7 + 1$ (curv. corr.) = 54.7 ($R_C < 15?$)

3) Specimen G-3

Pintle Rod No.	HR15N	Comment
	69.5	Indent made near clean end.
	70.5	
	55	Indent made near middle of roughened area.
	55.5	
	55	

Avg. HR15N for clean end = $70 + 1$ (curv. corr.) = 71 (R_C 22.5)

Avg. HR15N for middle of roughened area = 55.2 ($R_C < 15?$)

Date: Mar. 3, 1999

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RPP-5114 Rev 0

To: File

From: E. B. Schwenk

Subject: 7th CUT AT PINTLE ROD HARDNESS EVALUATION

On March 1, Paul Deichelborer called indicating that he had some additional failed pintle rods. I left for 2704 HV and accompanied Paul to 272-AW where we picked up the three rods from P. Bryant. All three rods had a blue tint and had cross-hatch, thread-chasing marks on their working ends. The cross-hatching had been placed on the rods before stress-relieving as they had the same blue tint. Based on information attached to each rod I gave them the identifications "FIT-1" (meaning failed-in-test), "RT5-10" (meaning failed retest 5 to 10-lb), and "98-034." Three used retaining rings were included with FIT, one with RT5-10 and one with 98-034. None of the rings left any significant indent in their respective rods.

Calibration: I used the $R_C = 26.5$ block with the following HR15N results.

1) 72, 2) 72.5 and 3) 72.5. Avg. = 72.3 [R_C 25, from Table 6 ASTM E 140]

a) FIT-1 HR15N measurements were made near center of rod.

1) = 68. 2) = 70, 3) = 70. Avg. = 69.3 + 1 (curv. corr.) = 70.3 [R_C 21]

I noted that the rod is slightly bent by always rolling to one position on a flat surface. It also did not want to turn easily in the hardness machine V-block support. I tried to get hardness measurements on the working end but was not successful due to the cantilever effect.

I then hung a weight on the working end of the rod in order to make hardness measurements closer (about 4-in. away) to the cross-hatched end. 4) = 71, 5) = 71.5. I then hung more weight and I was able to make two more measurements now about 2-1/2-in. away from the end. 6) = 72 7) = 71.

Avg. = 71.4 (4 rdgs) + 1 (curv. corr.) = 72.4 [R_C 25]

b) 98-034 This rod was also bent like FIT. Also could not rotate it in V-block without it rotating back to its desired neutral position. The hardness measurements were made near the rod center.

1) = 70, 2) = 70, 3) = 71. Avg. = 70.3 + 1 (curv. corr.) = 71.3 [R_C 23]

I then hung a weight on the working end as before.

4) = 72, 5) = 71 Avg. = 71.5 + 1 (curv. corr.) = 72.5 [R_C 25]

(both measurements made about 6-in. from working end).

I added more weight.

6) = 71.5, 7) = 71.5 Avg. = 71.5 + 1 (curv. corr.) = 72.5 [R_C 25]
(both measurements about ½-in. from end.)

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c) RT5-10 This rod would also not freely rotate to any given azimuthal position in the V-block.

1) = 71, 2) = 71 Avg. = 71 + 1 (curv. corr.) = 72 [R_C 24]
(measurements made near center of rod).

I put weight on end as above.

3) = 72.5, 4) = 73, 5) = 73.5 Avg. = 73 (made about 4-in. from end).

I added more weight.

6) = 71, 7) = 72, Avg. = 71.5 (indents made about 3-in. from end).
Avg. 5 rdgs) = 72.4 + 1 (curv. corr.) = 73.4 [R_C 27]

On 3/8/99 I cut off the working ends of all three rods in order to make measurements in the abraded areas.

Calibrated as usual on R_C = 26.5 block. 1) = 72, 2) = 73, 3) = 73, 4) = 73.
Avg. = 72.8 [R_C 26]

d) RT5-10

The first four measurements were made in the area closest to the end of the rod where the ring had lightly abraded the rod during insertion/removal.

1) = 69.5, 2) = 70, 3) = 70, 4) = 70. Avg. = 69.9 + 1 (curv. corr.) = 70.1 [R_C 20.5]

The next three measurements were made in the cross-hatched region where the ring had not disturbed the surface.

5) = 70, 6) = 71, 7) = 73. Avg. = 71.3 + 1 (curv. corr.) = 72.3 [R_C 25]

e) FIT-1

The measurements were made as in d) above.

1) = 71, 2) = 69, 3) = 71 Avg. = 70.3 + 1 (curv. corr.) = 71.3 [R_C 23]
(All made in ring-abraded area).

4) = 69, 5) = 70, 6) = 71 Avg. = 70 + 1 (curv. corr.) = 71 [R_C 22+]
(All made in cross-hatched, non-ring-disturbed area).

f) 98-034

Measurements made as above.

1) = 70.5, 2) = 70, 3) = 72 Avg. = 70.8 + 1 (curv. corr.) = 71.8 [R_C 24]
(ring-disturbed area).

4) = 74, 5) = 72, 6) = 71. Avg. = 72.3 + 1 (curv. corr.) = 73.3 [R_C 27]

Date: March 10, 1999

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RPP-5114 Rev 0

To: File

From: E. B. Schwenk

Subject: 8th CUT AT PINTLE ROD HARDNESS EVALUATION

Today I conducted HR15N hardness measurements on retaining rings from FIT-1, RT5-10, and 98-034. I also made measurements on new, failed rods 98-029, -033, -034, and -036.

Calibration on $R_C = 26.5$ block.

1) = 71.8, 2) = 71.5, 3) = 72. Avg. = 71.8 (= R_C 24, Table 6, ASTM E 140)

a) FIT-1

1) 1st Ring.

a) = 61, b) = 65, c) = 70, d) = 73.5, e) = 74, f) = 75, g) = 72.5

Avg. = 72.8 (last 4-rdgs) [= R_C 26, Table 6]

Note: I went counterclockwise around ring.

First two measurements are low – I'm not sure why. When I calibrated the machine I used the flat anvil. I then had to remove the N-Scale indenter in order to make room to fit the small dia. anvil in place. I then did one hardness indent in the 26.5 block before starting on the ring.

2) 2nd Ring

a) = 77 ?, b) = 74, c) = 71, d) = 73, e) = 72

Avg. = 72.5 (last 4 rdgs) [= R_C 25]

3) 3rd Ring

a) = 73, b) = 72.5, c) = 71, d) = 72 I went CCW.

Avg. = 72.1 [= R_C 24.5]

b) RT5-10

1) One ring

a) = 73, b) = 72.5, c) = 73.5 [CCW]

Avg. = 73 [= R_C 26]

c) 98-034

1) One Ring.

a) = 74.5, b) = 73, 3) = 72.5, d) = 75.5 [CCW]

Avg. = 73.9 [= R_C 28]

d) New Rod 98-029

1) = 70, 2) = 71, 3) = 70.5 (all taken near rod center)

$$\underline{\text{Avg.}} = 70.5 + 1 (\text{curv. corr.}) = 71.5 [\text{R}_C 23.5]$$

note: rod is bent slightly and is stable in V-block only at one orientation.

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e) New Rod 98-033

1) = 69, 2) = 69, 3) = 68.5 Rod not bent; sits in any position in V-block.

$$\underline{\text{Avg.}} = 68.8 + 1 (\text{curv. corr.}) = 69.8 (= \text{R}_C 20]$$

f) New Rod 98-034a

Rod is bent slightly; seeks one orientation.

1) = 70, 2) = 69.5, 3) = 70

$$\underline{\text{Avg.}} = 69.8 + 1 (\text{curv. corr.}) = 70.8 (= \text{R}_C 22]$$

g) New Rod 98-036

1) = 69.5, 2) = 70.5, 3) = 68, 4) = 68.5 Rod is bent

$$\underline{\text{Avg.}} = 69.1 + 1 (\text{curv. corr.}) = 70.1 [\text{R}_C 20.5]$$

h) Ring from 98-029

1) = 71, 2) = 70, 3) = 72 CCW

$$\underline{\text{Avg.}} = 71 [\text{R}_C 22.5]$$

i) Ring from 98-033

1) = 72, 2) = 72, 3) = 72. CCW

$$\underline{\text{Avg.}} = 72 [\text{R}_C 24]$$

j) Ring from 98-034a

1) = 69, 2) = 71, 3) = 72. CCW

$$\underline{\text{Avg.}} = 70.7 [\text{R}_C 22]$$

k) Ring from 98-036

1) = 69, 2) = 70, 3) = 71. CCW

$$\underline{\text{Avg.}} = 70 [\text{R}_C 20.5]$$

More new rods and rings.

a) 98-010 Ring

1) = 69, 2) = 70, 3) = 74, 4) = 72 CCW

$$\underline{\text{Avg.}} = 71.3 [\text{R}_C 23]$$

b) 98-013 Ring

1) = 71.5, 2) = 75, 3) = 72.5, 4) = 74. CCW first then back due to curvature.

$$\underline{\text{Avg.}} = 73.3 [\text{R}_C 27]$$

c) 98-016 Ring

1) = 64 ?, 2) = 74, 3) = 74, 4) = 71.5. I went CCW on 1st 3 then backed up due

$$\underline{\text{Avg.}} = 73.2 (\text{avg. of 2-4}) [\text{R}_C 26.5] \quad \text{to curvature.}$$

d) 98-010 Rod

1) = 70, 2) = 70, 3) = 70. Rod is bent slightly. Rdgs taken near center.
Avg. = $70 + 1$ (curv. corr.) = 71 [R_C 22.5]

e) 98-013 Rod

1) = 70, 2) 69.5, 3) = 70 Rod is bent slightly.
Avg. = $69.8 + 1$ (curv. corr.) = 70.8 [R_C 22]

f) 98-016 Rod

1) = 69, 2) = 71, 3) = 70. Rod is bent slightly.
Avg. = $70 + 1$ (curv. corr.) = 71 [R_C 22.5]

3/11/99

I had Tom DeLucchi cut off the ends of new rods 98-029, 98-033, 98-034a, and 98-306. The ends were about 1-1/2 to 2-in. long. This was done in order to see if these rods had any significant difference in hardness between the middle and their working end (see significant difference in hardness between middle and end for FIT-1, RT5-10, and 98-034).

Calibration of HR15N on R_C 26.5 block. 1) = 72.5, 2) = 73, 3) = 73.
Avg. = 72.8 [R_C 26]

a) Rod End 98-029

1) = 69, 2) = 58?, 3) = 72, 4) = 69. These rdgs taken in ring-abraded area.
Avg. = 70 (3 rdgs) + 1 (curv. corr.) = 71 [R_C ≈22.5]

5) = 68, 6) = 68, 7) = 70.5. These rdgs taken in cross-hatched but non ring-abraded area.

Avg. = 68.8 (3 rdgs) + 1 (curv. corr.) = 69.8 [R_C 20]

b) Rod end 98-033

1) = 70, 2) = 72, 3) = 71.5. (These rdgs taken in ring-abraded area)
Avg. = $71.5 + 1$ (curv. corr.) = 72.5 [R_C 25]

4) = 70.5, 5) = 69, 6) = 70 (These rdgs taken in cross-hatched, non ring-abraded area)
Avg. = $70.5 + 1$ (curv. corr.) = 71.5 [R_C 23+]

c) Rod end 98-034a

1) = 68.5, 2) = 68, 3) = 69. (Ring-abraded area)
Avg. = $68.5 + 1$ (curv. corr.) = 69.5 [R_C 20-]

5) = 68, 5) = 70.5, 6) = 71 (Cross-hatched area, non ring-abraded)
Avg. = $69.8 + 1$ (curv. corr.) = 70.8 [R_C 22]

d) Rod end 98-036

1) = 74, 2) = 74, 3) = 71. (Ring-abraded area)

Avg. = $73 + 1$ (curv. corr.) = 74 [R_C 28]

4) = 70, 5) = 71, 6) = 70. (Cross-hatched, non ring-abraded area)

Avg. = $70.3 + 1$ (curv. corr.) = 71.3 [R_C 23]

2: 45 PM. I went back to the high bay and got Marty Casto to cut off the "grab end" of the above four rods. I did this to see if there is an end-to-end variation in hardness. The pieces are about 3-4-in. long.

a) Rod end 98-029-1 (Grab end) The hardness indents started about 3/4-in. from the weld joining the rod to the grab end.

1) = 66, 2) = 67, 3) = 68.5, 4) = 66.5

Avg. = 67 (4 rdgs) + 1 (curv. corr.) = 68 [R_C <19]

b) Rod end of 98-033-1 (grab end) The indents started about 3/4-in. from weld.

1) = 69, 2) = 68, 3) = 69.

Avg. = 68.7 (3 rdgs) + 1 (curv. corr.) = 69.7 [R_C 20]

c) Rod end of 98-034a-1 (grab end) The indents started about 3/4-in. from weld.

1) = 67.5, 2) = 70, 3) = 70.5, 4) = 70, 5) = 68 Rdgs 1-4 progressed away from the weld; because the numbers seemed to be monotonically increasing, I backed up and made indent 5 near no. 1 rdg.

Avg. = 69.2 (5 rdgs) + 1 (curv. corr.) = 70.2 [R_C 21]

d) Rod end of 98-036-1 (grab end) Ditto above.

1) = 68.5, 2) = 69, 3) = 69, 4) = 69

Avg. = 68.9 (4 rdgs) + 1 (curv. corr.) = 69.9 [R_C 20]

Calibration check. R_C = 26.5 block. 1) = 72, 2) = 71, 3) = 72.

Avg. = 71.7 (3 rdgs) [R_C 24-]

Date: March 14, 1999

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To: File

From: E. B. Schwenk

Subject: **COMPARISON OF ROD HARDNESS DATA (9th Cut)**1) 5-Notches 1150° F for 3-hours, Knurled Rods (1 end) [R_C 16-17, Beaver Data]

Rod No.	Location	Hardness			Comment
		Max	Avg.	Min	
5N-1	Smooth	24	23+	21.5	
	Knurled & Ring abraded	40	35	30	Much harder in knurled region
5N-2	Smooth	22.5	19.5	< 19	
	Knurled + ring abraded	44	33.5	20	Much harder in knurled region.

2) 4-Notches 1050° F-3 hours [R_C 22, Beaver Data]

Rod No.	Location	Hardness			Comment
		Max.	Avg.	Min.	
4N-1	Machine- brushed	32	27.5	24	
	Lightly oxidized	27	25.5	24	
	Machine brushed & ring scraped	30	28	26	
	Lightly oxidized & ring-scraped	39	35	30	

4N-2	Location	Hardness			Comment
		Max.	Avg.	Min.	
	Machine- brushed	30.5	29	26	
	Lightly oxidized	26	24	22.5	
	Machine- brushed & ring- scraped	30	29	26	

3) 6-Notches 1250° F – 3 hours [R_C 13, Beaver Data]

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Rod No.	Location	Hardness			Comment
		Max.	Avg.	Min.	
6N-1	Smooth	20.5	< 19	< 19	
	Filed area	< 19	< 17	< 16	
	Knurled end non ring abraded	30	29	26	
	Knurled end & ring abraded	30	28.5	27	
6N-2 both ends knurled	Smooth	20	< 17	< 16	
	Knurled end w 6-notches	--	--	--	Hardness likely greater; not possible to get good measure
	Knurled end (opposite end)	26	22 +	< 18	
	Knurled + ring abraded	--	40	--	Only one measurement made.

4) 7-Notches (no Knurling) 1100° F – 3 hours [R_C 20-21, Beaver Data]

Rod No.	Location	Hardness			Comment
		Max.	Avg.	Min.	
7N-1	Machine-brushed region	38	27.5	22	
	Lightly oxidized area	22.5	22.5	22.5	
	Ring abraded area				Could not get good rdgs.
7N-2	Machine brushed area	30	27.5	26	
	Filed	--	30	--	
	Lightly oxidized	30	29	28	
	Ring-scraped	29	28.5	28	

5) Five Brown-tint Rods (no Knurling but w thread-chasing) 1100° F 3 hrs [No Beaver hardness data]

Rod No.	Location	Hardness			Comment
		Max.	Avg.	Min.	
LB-1	Smooth	22.5	21.5	20.5	
	Ring-abraded + thread chased	<20	< 19	< 18	
	Non ring-abraded + thread chased	42	30	< 18	Variation probably due to lands & grooves.
LB-5	Smooth	26	23.7	20.5	
	Thread-abraded & ring abraded	22.5	About 19	< 17	

6) Light Blue Rods (5) 1100° F-3 hrs. [No Beaver Hardness data]

Rod No.	Location	Hardness			Comment
		Max.	Avg.	Min.	
B-1	Smooth	28	21	20	
	Ring abraded	< 20	< 19	< 18	
B-2	Smooth	22	20.5	< 20	

Date: March 17, 1999

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To: File

From: E. B. Schwenk

Subject: 10TH CUT AT PINTLE ROD HARDNESS EVALUATION

Today I attempted to complete the hardness evaluation on 98-016, 98-013, RT5-10, 98-010, and 98-034 so that I had end-to-end measurements of hardness on all these rods. I forgot FIT-1.

Calibration on $R_C = 26.5$ block. 1) = 72.5, 2) = 73.5, 3) = 73. Avg. = 73
(= R_C 26, ASTM E140, Table 6)

a) 98-016-1 (Grab End)

1) = 43.5 (low) 2) = 61, 3) = 68, 4) = 68, 5) = 69. Note 1st two indents were in a "different" quality area.
Avg. = $68.3 + 1$ (curv. corr.) = 69.3 ($R_C < 20$)

b) 98-016 Working end

1) = bad (misaligned), 2) = 68.5, 3) = 68.5 3) = misaligned (56), 4) = 68.5, 5) = 68.5, Avg. = $68.5 + 1$ (curv. corr.) = 69.5 ($R_C < 20$).

6) = 70.5, 7) = 71, 8) = 70 (all in thread-abraded area) Avg. = $70.5 + 1$ (curv. corr.) = 71.5 (R_C 22.5)

9) = 71, 10) = 72, 11) = 73.5 (all in thread-abraded + ring-scraped).
Avg. = $72.2 + 1$ (curv. corr.) = 73.2 (R_C 26.5)

c) 98-013-1 (Grab end)

1) Misaligned, 2) = 70, 3) = 70.5, 4) = 72, 5) = 71. Avg. = $70.8 + 1$ (curv. corr.) = 71.8 (R_C 24)

d) 98-013 Working end

1) = 69, 2) = 69, 3) = 71. Avg. = $69.7 + 1$ (curv. corr.) = 70.7 (R_C 22)

4) = 66, 5) = 69, 6) = 70 (all thread-abraded region) Avg. = $68.3 + 1$ (curv. corr.) = 69.4 ($R_C < 20$)

7) = 70, 8) = 70, 9) = 72 (ring abraded + thread chased) Avg. = $70.7 + 1$ (curv. corr.) = 71.7 (R_C 23.5)

e) RT5-10-1 (Grab end)

1) = 70, 2) = 69.5, 3) = 76 (high?). Avg. = $71.9 + 1$ (curv. corr.) = 72.9 (R_C 26)

f) 98-010-1 (Grab end)

$$1) = 69.5, 2) = 69.5, 3) = 69. \text{ Avg.} = 69.3 + 1 (\text{curv. corr.}) = 70.1 (R_C 20.5)$$

g) 98-010 Working End

$$1) = 69, 2) = 70.5, 3) = 71. \text{ Avg.} = 70.2 + 1 (\text{curv. corr.}) = 71.2 (R_C 22)$$

$$4) = 68, 5) = 71, 6) = 70 (\text{all Thread-chased area}) \text{ Avg.} = 69.8 + 1 (\text{Curv. corr.}) = 70.8 (R_C 22)$$

$$7) = 67.5, 8) = 69, 9) = 71 (\text{all ring-scraped + thread chased}). \text{ Avg.} = 69.2 + 1 (\text{curv. corr.}) = 70.2 (R_C 21)$$

h) 98-034-1 (Grab End)

$$1) = 69, 2) = 69, 3) = 70. \text{ Avg.} = 69.3 + 1 (\text{curv. corr.}) = 70.3 (R_C 21).$$

i) 98-034 Working End

$$1) = 69, 2) = 69, 3) = 69. \text{ Avg.} = 69 + 1 (\text{curv. corr.}) = 70 (R_C 20.5)$$

$$4) = 67, 5) = 66.5, 6) = 67 (\text{All thread-chased}). \text{ Avg.} = 66.8 + 1 (\text{curv. corr.}) = 67.8 (R_C < 18)$$

$$7) = 69.5, 8) = 68.5, 9) = 70 (\text{All ring-abraded + thread chased}). \text{ Avg.} = 69.3 + 1 (\text{curv. corr.}) = 70.3 (R_C 21)$$

Note: I think I just repeated 98-034 working end as there are another 6 or so indents on the rod.