Honeywell

Mechanical Testing Development for Reservoir Forgings

Federal Manufacturing & Technologies

E. G. Wenski

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MECHANICAL TESTING DEVELOPMENT

FOR RESERVOIR FORGINGS

E. G. Wenski

Published May 2000

Final Report

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Abstract

The goal of this project was to determine the machining techniques and testing capabilities required for mechanical property evaluation of commercially procured reservoir forgings. Due to the small size of these specific forgings, specialized methods are required to adequately machine and test these sub-miniature samples in accordance with the requirements of ASTM-E8 and ASTM-E9. At the time of project initiation, no capability existed at Federal Manufacturing & Technologies (FM&T) to verify the physical properties of these reservoirs as required on the drawing specifications. The project determined the sample definitions, machining processes, and testing procedures to verify the physical properties of the reservoir forgings; specifically, tensile strength, yield strength, reduction of area, and elongation. In addition, a compression test method was also developed to minimize sample preparation time and provide a more easily machined test sample while maintaining the physical validation of the forging.

Summary

Gas reservoirs are a major expendable component in the nuclear weapon stockpile. These components must be metallurgically sound and physically robust to eliminate the possibility of any gas leakage during the life of the reservoir. To obtain these desired characteristics, various physical parameters are designed into the high-energy forgings to ensure quality and ultimate physical strength.

Unfortunately, with the shutdown of the Department of Energy’s Oxnard facility and the push to commercialize forging procurement, a certain amount of technological knowledge was lost in regard to the quality acceptance of various miniature forgings. This loss consisted mainly of processing of test samples and the determination of mechanical properties using sub-miniature tensile samples.

This project focused on the development of various machining and testing procedures using these miniature samples. Five separate rounds of test samples were defined, machined, and tested for the project. Results showed that the small sub-miniature samples provide good correlation to the material specification configuration and that a compressive sample can in some cases provide adequate comparative results.

Discussion

Scope and Purpose

The scope of this project was to determine the machining and testing parameters required for sub-miniature tensile and compression samples for quality acceptance of small commercial reservoir forgings. Various work instructions, processing documents, physical tooling, and testing methodology were developed to satisfy the drawing requirements for obtaining the mechanical properties of these forgings. Processes developed from this work will be used to validate the functionality of the reservoir forging and accept the material into the production system.

Activity

Background

Due to budget concerns, the Department of Energy closed the Oxnard facility in the summer of 1996. This facility produced the majority of all high-energy forgings used in the manufacture of gas reservoirs. In addition, Oxnard conducted numerous physical tests on the reservoir forgings to verify the processing and meet the stringent DOE quality requirements.

After the facility was closed, a number of qualification procedures failed to be passed on to Honeywell Federal Manufacturing & Technologies (FM&T), specifically, the manufacturing process of the small sub-miniature tensile samples and the testing procedures required for the determination of the mechanical properties.

Hence, to re-establish the lost capability, FM&T initiated a three-phase approach to verify the machining and testing parameters needed for the acceptance process. This approach focused on the machining and testing of three different test configurations: a standard MS tensile sample, a sub-miniature tensile sample, and a miniature ASTM compressive sample.

Numerous bars of MS 9851331-01-804-Z 304L stainless steel material were acquired from production stores for the evaluation. This material was chosen because most high-energy forgings are made from 304L stainless steel. It also provides a more difficult material to adequately machine, and care needs to be taken to ensure a quality test sample.

Test Methodology

To adequately obtain the necessary mechanical properties from the miniature forgings, a specialized test sample was developed for the project. This sample was based on an earlier design from Oxnard and was modified to correlate with the sample requirements from ASTM-E8 and the material specification. This sample was proportionally consistent to both specifications. A mechanical drawing of the miniature test sample is provided in Figure 1. (All figures appear following the text.)

For comparison purposes and to define the size effects on the results from the miniature sample, additional tests were conducted to compare the sub-sized sample to the standard sample from the material specification. This R3 sample size is defined from ASTM-E8, and the mechanical drawing of this sample is provided in Figure 2. In addition, the R5 test sample from the MS specification was also used to correlate the results to the miniature sample. This sample is proportional to the R3 sample with an overall length of only 1.6 inches, a gage length of 0.45 inch, and a diameter of 0.113 inch. The R3 sample was used in test rounds I-III and the R5 test sample was used in test rounds IV and V.

It quickly became apparent after numerous machining cycles on the miniature sample that a more manufacturable sample was required to verify the properties of the forging. Therefore, a compression sample was deemed adequate for this purpose. This sample configuration would only provide yield strength data, but was sufficient to quantify the strength of the forging. A specialized sample was developed in accordance with ASTM E9, and a mechanical drawing of this compression sample is given in Figure 3.

Mechanical testing of the samples was conducted on either an Instron Model 4500 or 5500 test system operating with Series IX software with a 5,000 or 20,000-lbs load cell. These systems are computer-controlled with data acquisition rates up to 500 samples per second. All tensile machines were calibrated and verified acceptable under the requirements of ASTM-E4. Threaded specimen holders were used with 24-inch extension rods to attach to the test machine and minimize the bending stress on the test samples.

To accurately obtain the strain on the miniature samples during testing, an extensometer was purchased with an active gage length of only 0.250 inch. This was an Epsilon Model 3442 extensometer provided with a quick-attachment kit. A mechanical drawing of this extensometer is given in Figure 4. This extensometer was calibrated before each test sequence using an MTS Model 650.03 dial-micrometer calibrator. This calibrator was used to verify the displacement of the extensometer up to 50% strain. Beyond this strain level, the crosshead displacement was used by the test system to record the strain during the test. Strain measurements were made on the R3 and R5 samples using MTS extensometers with 1.0 and 0.5 gage lengths and were calibrated using the same micrometer calibrator.

Punch marks were made in all R3 and R5 test samples, and dots were laser scribed in the miniature test samples to avoid any negative effect on the failure of the samples. Reduction of area and total elongation measurements were completed post-test using a vise mechanism to re-assemble the test sample. This vise allowed for the sample to be re-assembled for the required measurements. The vise assembly was then installed onto a Deltronic Model DH14 Optical Comparitor with an MPC-4E coordinate system for the necessary elongation measurements. A mechanical drawing of this vise mechanism is given in Figure 5. In addition, this same setup was used on all samples to determine the reduction of area.

Compression testing was conducted using a sub-press to ensure positive alignment of the test plattens. Custom conical hardened plattens were designed for the project to allow attachment of the extensometer on the test sample. This provided a more consistent test result by eliminating the compliance of the test frame and sub-press. Lubrication on the ends of the samples using a moly-disulfide powder/grease was also completed to minimize "barreling" of the test sample. The sub-press was a highly polished ram assembly and provided less that 1.0 pound of "drag" bias on the overall test results.

Machining Methodology

Machining of any tensile sample is not a simple task, especially since different machining techniques can drastically alter the mechanical test results. These changes occur in localized heating of the surface of the material and a metallurgical change that occurs through strain hardening. At the beginning of the project, it was anticipated that general parameters used to machine test samples in accordance with the material specification would be adequate for the testing needs. Unfortunately, it became quickly apparent from test rounds II and III that those MS guidelines were not acceptable for consistent test sample preparation.

Hence, numerous discussions were made with Lawrence Livermore National Laboratory (LLNL) to provide a detailed procedure to machine these test samples. LLNL had extensive experience in this testing realm, and their inputs were incorporated into written work instructions for the machining of the miniature test sample configuration. It has been shown that the final three passes on the test sample are the most critical in the entire machining process where strain hardening can occur in the surface. Therefore, an effort was made to document and control the machining process to ensure good quality test results. These detailed instructions were defined by the Model Shop and are provided in Figures 6-8.

Tensile samples for rounds I through III were machined on a Monarch C-10 lathe with a tracer attachment. Samples for rounds IV and V were machined on a CNC lathe to better control the process. All compressive samples were machined on a similar Monarch lathe without the use of a tracer and later on the same CNC lathe to better control the process.

Results

Five separate test rounds were used in the project to develop the sample configuration, the machining guidelines, and test parameters. Testing was conducted over a period of a year in an attempt to develop a consistent sample and to incur the typical variation in machine processing and mechanical testing. It also allowed for additional development of the different steps in the processing.

All samples were machined out of the same bar of material per round using material between 0.250" and 0.375" in diameter. Test rounds I through III were made from 0.375" diameter stock, and rounds IV and V used 0.250" diameter stock. Hence, R3 samples were made for rounds I, II and III, and R5 samples were made for rounds IV and V. This change in sample configuration was made to quantify the size variation effects in the test samples and provide the machinist a more difficult sample to manufacture. It would also represent a sample size that would mimic the expected size of the bulk sample from the smallest reservoir forging.

Generally, ten samples were used to define the mechanical properties of the test rounds. All samples were segregated out before physical testing to eliminate improper sample configurations from the test data. No sample data was removed from the post-test statistical analysis.

Tables 1-15 contain the actual test values calculated from the physical analysis. (All tables appear following the text.) Tensile parameters included modulus of elasticity, 0.2% yield strength, tensile strength, elongation, and reduction of area. Since the compression tests were conducted to approximately 2% strain, only modulus of elasticity and 0.2% yield strength were calculated from these tests. A summation of the results is presented in Table 16.

Generally, all of the stress-strain curves for the individual tests were as expected. No major discrepancies were seen in the curves and/or the test data. For the most part, the variation in the results was typical of the standard process in accordance with ASTM-E8.

A review of the test data from Table 16 denotes the following notables:

- A definite difference in property determination existed between the first three rounds and rounds IV and V. The R3 sample appeared to provide a more consistent sample than the R5 sample. This was expected since metallurgical changes to the material are minimized as the sample size increases. More bulk material was removed in the machining of the miniature sample for these three rounds, obviously affecting the material properties of the bar stock. Tensile modulus of elasticity for all test rounds was between 26 to 30 msi as compared to 28.5 msi as noted for 304L in published journals. For the most part, these modulus values were in an acceptable range for the material and the test process.
- Tensile strength was lower on the miniature sample for rounds I through III and was higher in rounds IV and V. This result was expected after implementation of the machining specifications of Figure 6.
- The 0.2% yield tensile strength was suprisingly consistent in the last three rounds, especially with the variation of modulus of elasticity. Hence, yield strength qualification using the miniature test sample appears to be adequate for the application.
- For the most part, the elongation of the material was as expected in the last two rounds. Typically, the material fails to elongate with the smaller-sized sample due to the inability of the material to plastically flow. Hence, smaller elongation values with higher tensile strengths are usually obtained. In addition, a change was made in the miniature sample definition to modify the spacing on the laser dots. This change from 0.25 inch to 0.24 inch was made to bring the configuration more in line with the ASTM-E8 specification. It is hoped that this modification will provide better elongation results by eliminating the influence of the transition zone between the gage length and the specimen threads.
- The reduction of area calculation was quite acceptable for all test rounds and should provide good test data for the forgings.
- The compressive sample failed to provide consistent results in the calculation of the modulus of elasticity and the 0.2% compressive yield strength. Round V produced the best comparable yield strength result, but was influenced by the high modulus calculation for the test round. Obviously, more work is needed in this test regime to eliminate any potential bending in the compression sample while in the sub-press.

Accomplishments

The primary goal of the project was to determine the mechanical properties of a miniature reservoir forging when a standard, full-sized ASTM sample is not obtainable. To meet this goal, five specific tasks were accomplished for the project:

1. A process definition for both a tensile and compressive test samples was defined. This definition, based on the ASTM-E8 requirement, was documented in this report and will become a working standard for procurement of small reservoir forgings.
2. Due to the lack of control in the machining process, a number of Record and Drawing Specifications were recorded to eliminate the major source of variation in the process. Three machining procedures are documented in the report for the miniature tensile, miniature compressive, and standard-sized R3/R5 test samples.

- Specific test procedures, equipment, and methodology were developed to adequately verify mechanical properties of these test samples. Instron test methods were generated using the miniature Epsilon extensometer, and specific hardware was designed and developed to maintain process control during testing.
- A correlation study was completed to verify the differences in the three test sample configurations. This analysis showed that the micro-tensile sample generally produces test results with both higher tensile strengths and consistent yield strengths. Primarily, these results are due to the non-standard size relationship of the sample and the inability of the material to adequately flow during plastic deformation. This tensile strength difference was anywhere from +/- 4.5 percent and +/-1.5 percent higher in yield strength using the micro-tensile sample. Elongation and Reduction of Area results were acceptable using the miniature test sample.
- The compression test sample failed to produce consistent results from the five test rounds. Modulus of elasticity varied considerably from test to test, therefore affecting the calculation of the 0.2% yield strength. Based on this work, the compression sample provides the least effective way to verify forging physical properties. It is hoped that additional work in this area will provide more consistent results.

Future Work

Presently work is under way to procure a new miniature CNC lathe to manufacture the miniature tensile samples. This computer-controlled machine should provide a more consistent test sample and minimize the possibility of localized heating on the material. It will also eliminate the variability of the machining operator on the test results.

In addition, changes will be made to the conical plattens on the sub-press for compression testing. These new plattens will be made of silicon carbide to ensure a more load-resistant material for the ends of the compression sample. It will also mimic the platen requirement of ASTM-E9 and hopefully provide better correlation between the loading modes.

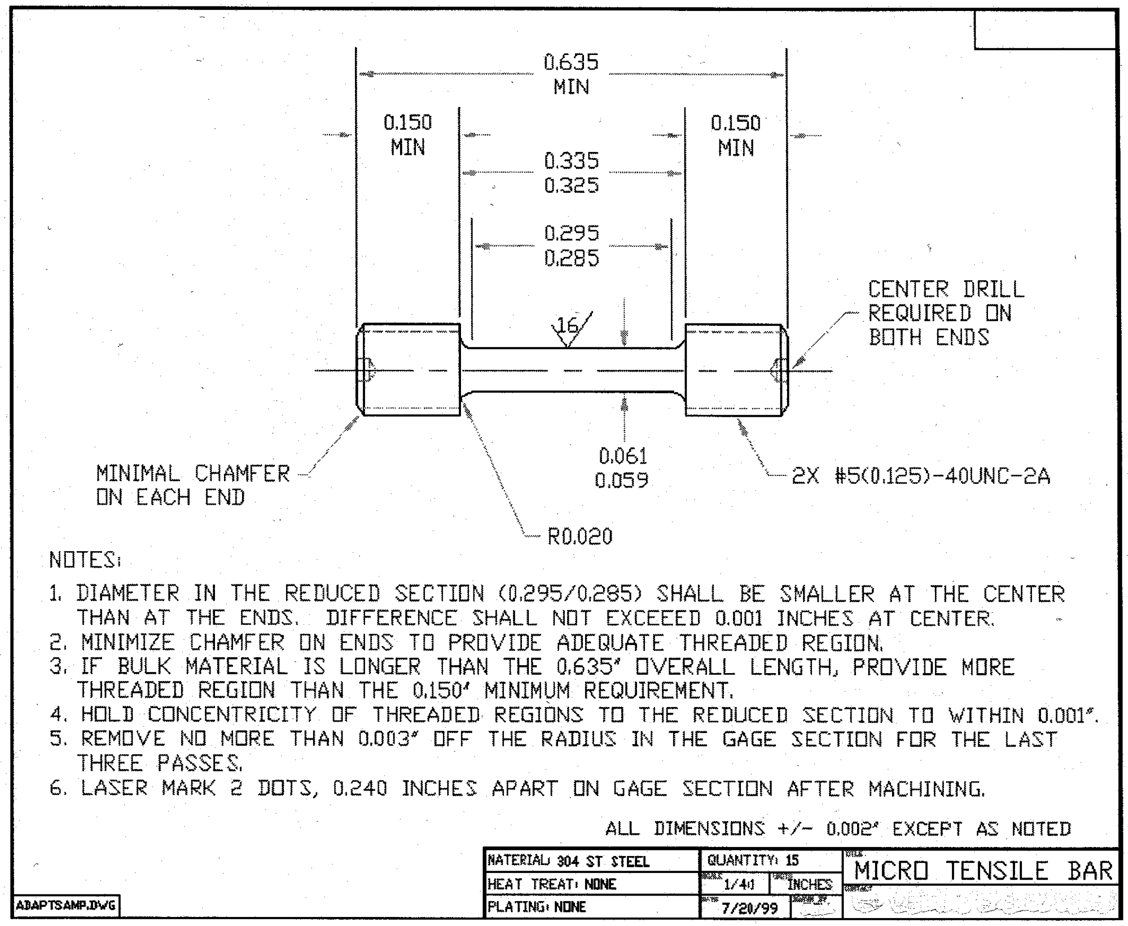
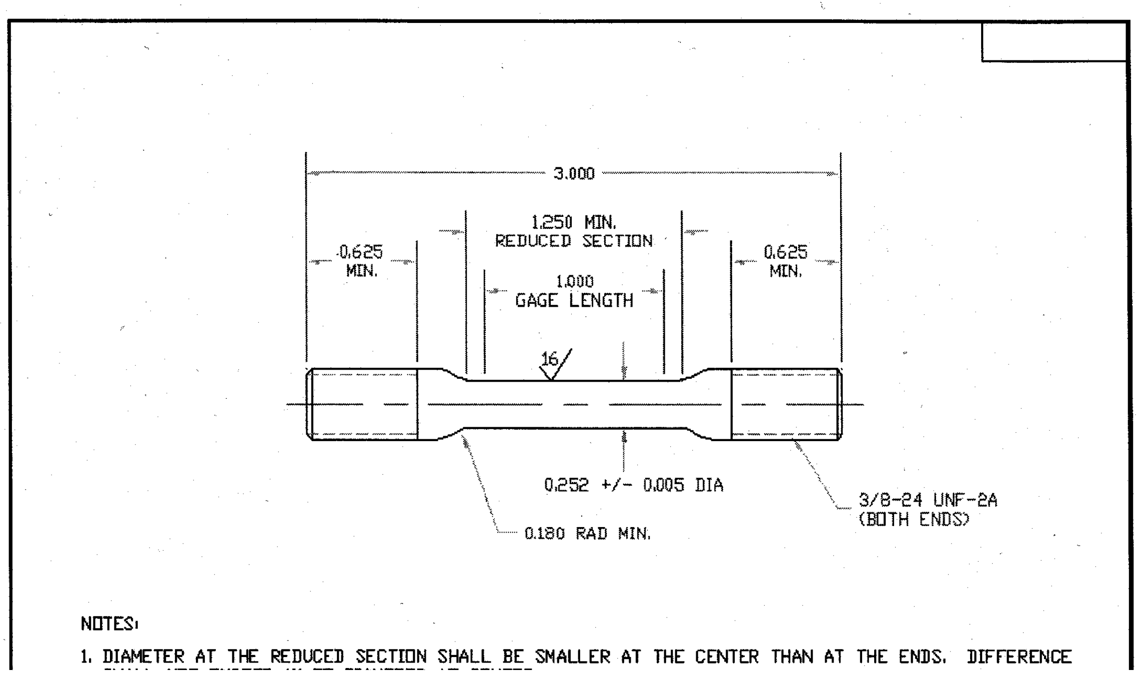


Figure 1. Drawing of the Miniature Tensile Sample Used in the Evaluation



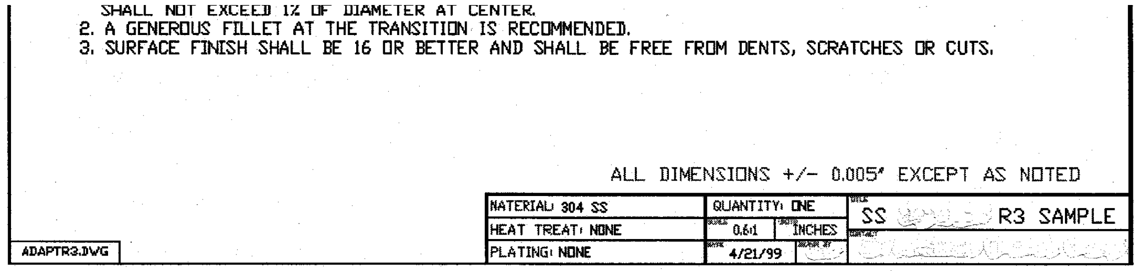


Figure 2. Drawing of the R3 Tensile Sample Used in the Evaluation

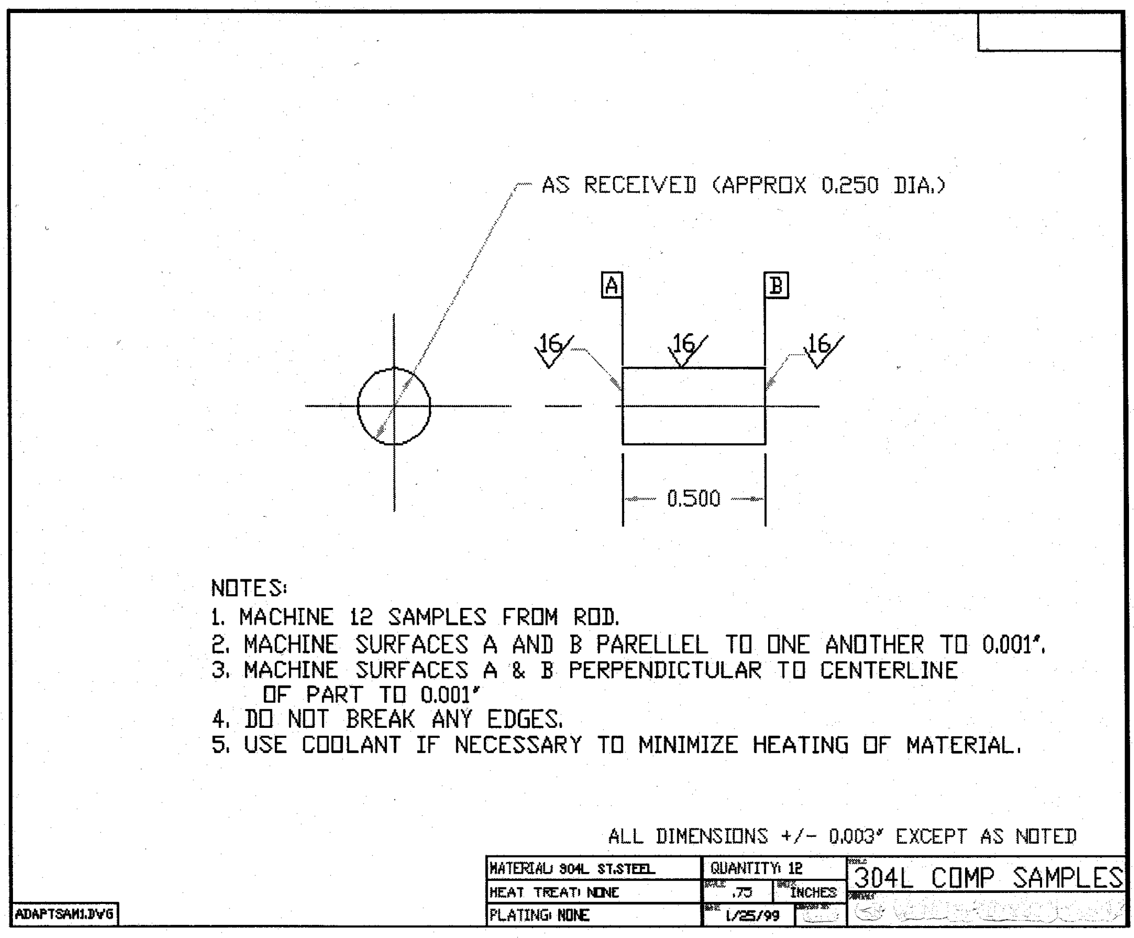


Figure 3. Drawing of the Miniature Compression Sample Used in the Evaluation

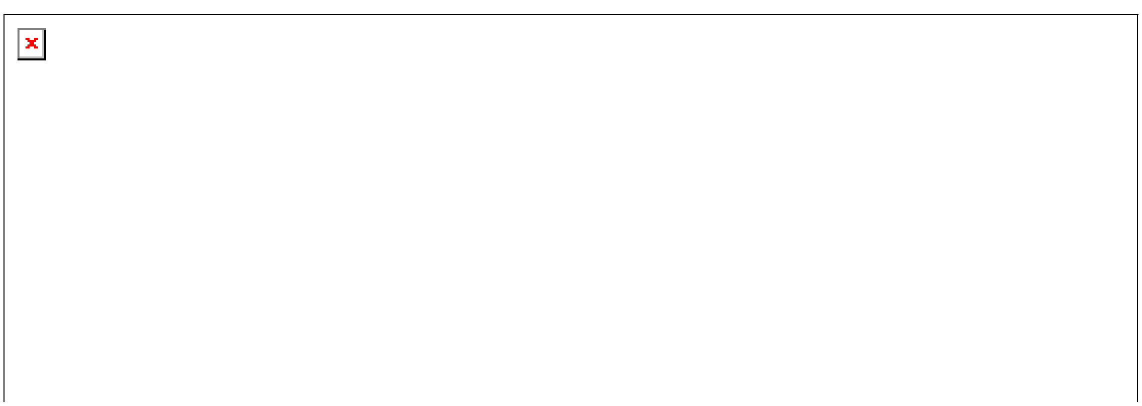
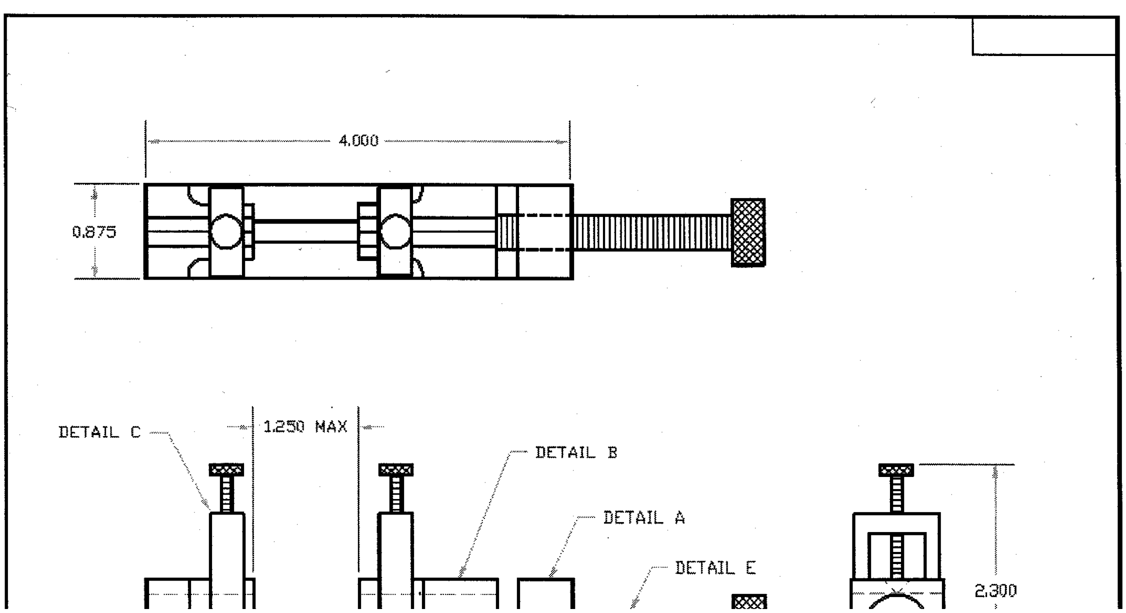


Figure 4. Drawing of the Epsilon Miniature Extensometer Used in the Evaluation



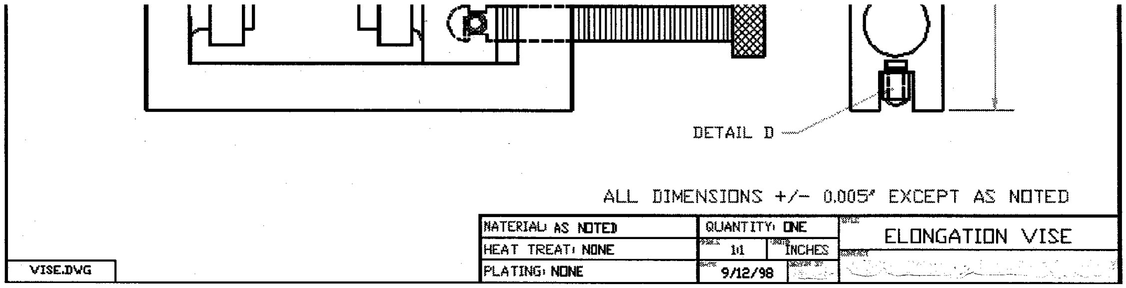


Figure 5. Drawing of the Miniature Vise Mechanism Used to Determine Elongation for the Evaluation

[redacted] -UNCLASSIFIED UNLESS OTHERWISE SPECIFIED- INITIALS:

PROCESS RECORD	PART NAME	PART NO.	ISSUE	W.O. N
	Micro-tensile	none	A	
AND DRAWING	PROCESS ENGINEER	MATERIAL		
		304L rod		

Material being supplied is Stainless steel (304L) 0.375" dia. Rod or 0.250" dia. (Maintain

Machine being used: Monarch lathe with tracer attachment and standard lathe for threadi

Op #

10 Holding material in an appropriate collet or using faceplate and dog, face and turn blanks.

Add a small center hole in one or both ends and use as needed.

Turn blank to 0.125"dia. and a length of 0.700".

20 Place blank in a collet and using a tail stock center, thread both ends, #5-40 UNC-2A. (0.

30 Place threaded blank in an appropriate collet and using a tail stock center and Micro-tensi

Turn the necked-down section of the sample. The dia. @ center is to be 0.060+/-0.001" a
should not be more than 0.001" taper to either end. The gage area is to be a #16 surface f
Cuts should be optimized to remove material in a manner not to work harden the sample.
The final two finish cuts of the gauge diameter should not exceed 0.003" per pass.
Use fine emery cloth to lightly polish the gauge area to blend machine marks.

35 Laser mark two (2) dots 0.240" apart centered within the 0.295" gage area.

40 Clean with alcohol and package to protect parts. (label samples clearly)

50 Ship

Figure 6. Process Record and Machining Specification for the Micro-Tensile Sample Used for the Evaluation

[redacted] -UNCLASSIFIED UNLESS OTHERWISE SPECIFIED- INITIALS:

PROCESS RECORD	PART NAME	PART NO.	ISSUE	W.O. N
	R5 Sample	none	A	
AND DRAWING	PROCESS ENGINEER	MATERIAL		
		304L rod		

Material being supplied is: Stainless steel (304L) 0.375" dia. Rod or 0.250" dia. (Maintai

Machine being used: Monarch lathe with tracer attachment and standard lathe for threadi

Op #

10 Holding material in an appropriate collet or using faceplate and dog, face and turn blanks.

Add a small center hole in one or both ends and use as needed.

Turn blank to requirements of MS 9949050 for either R3 or R5 sample.

20 Place blank in an appropriate collet and using a tail stock center, thread both ends, ¼-28 U

30 Place threaded blank in an appropriate collet and using a tail stock center and R3/R5 temp

turn the necked-down section of the sample. The dia. @ center is noted on the MS and th

should not be more than 0.0013" taper to either end.

Cuts should be optimized to remove material in a manner not to work harden the sample.

The final two finish cuts of the gauge diameter should not exceed 0.003" per pass.

Use fine emery cloth to lightly polish the gauge area to blend machine marks.

40 Clean with alcohol and package to protect parts. (label samples clearly)

50 Ship

Figure 7. Process Record and Machining Specification for the R5 Test Sample Used for the Evaluation

PROCESS RECORD	PART NAME	PART NO.	ISSUE	W.O. N
	Comp. Sample	none	A	
AND DRAWING	PROCESS ENGINEER		MATERIAL	
			304L rod, 3/8" dia.	

Material being supplied is Stainless steel (304L) .375" dia. rod.

Machine being used, Monarch C-10 lathe.

Op #

10 Holding material in an appropriate collet, face and turn blanks.

Sets: .016" R. lathe tool --- (roughing operation)

.008" R. lathe tool --- (finishing operation)

Run @ .0005" lead/ 300 SFM (approx. 4000 rpm)

20 Polish lightly with 600 grit emery cloth.

Part off leaving material for facing.

30 Locate against stop in collet and face to length.

(the customer has ask not to break edges.)

40 Clean with alcohol and package to protect parts.

50 Identify with P/N if applicable. Ship

Figure 8. Process Record and Machining Specification for the Micro-Compressive Sample Used for the Evaluation

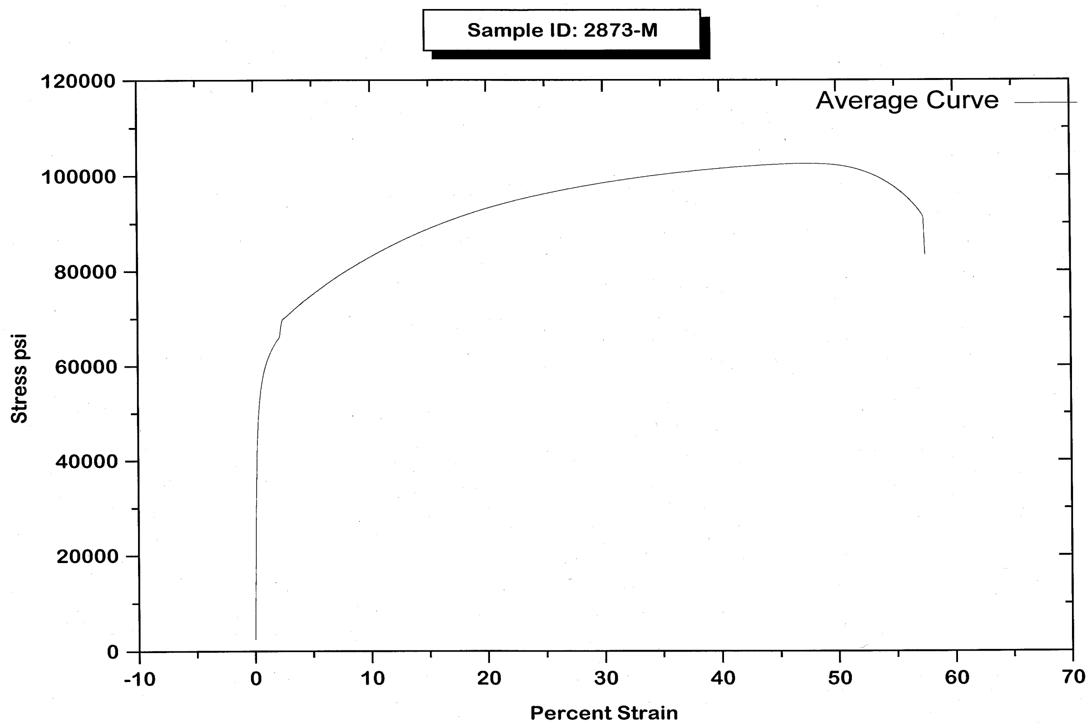


Figure 9. Average Stress-Strain Response of 304SS for the Micro-Tensile Sample (Round I)

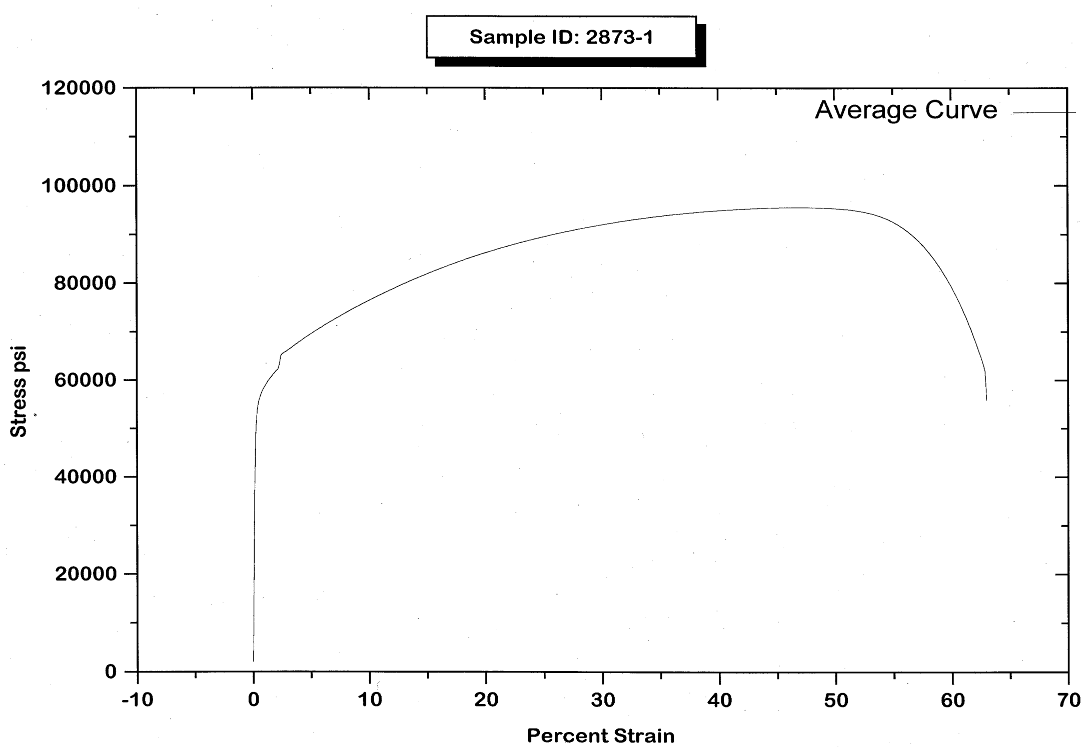


Figure 10. Average Stress-Strain Response of 304SS for the R3 Tensile Sample (Round I)

Figure 11. Average Stress-Strain Response of 304SS for the Miniature Compressive Sample (Round I)

Figure 12. Average Stress-Strain Response of 304SS for the Miniature Tensile Sample (Round II)

Figure 13. Average Stress-Strain Response of 304SS for the R3 Tensile Sample (Round II)

Figure 14. Average Stress-Strain Response of 304SS for the Miniature Compressive Sample (Round II)

Figure 15. Average Stress-Strain Response of 304SS for the Miniature Tensile Sample (Round III)

Figure 16. Average Stress-Strain Response of 304SS for the R3 Tensile Sample (Round III)

Figure 17. Average Stress-Strain Response of 304SS for the Miniature Compressive Sample (Round III)

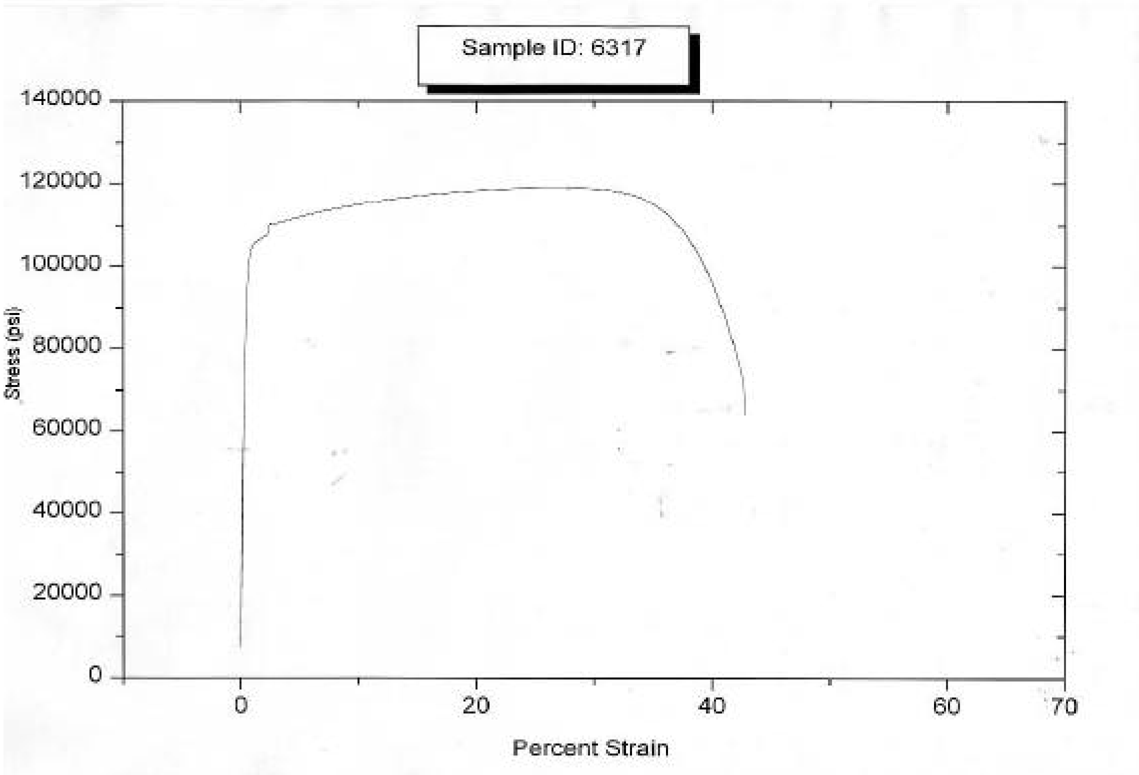


Figure 18. Average Stress-Strain Response of 304SS for the Miniature Tensile Sample (Round IV)

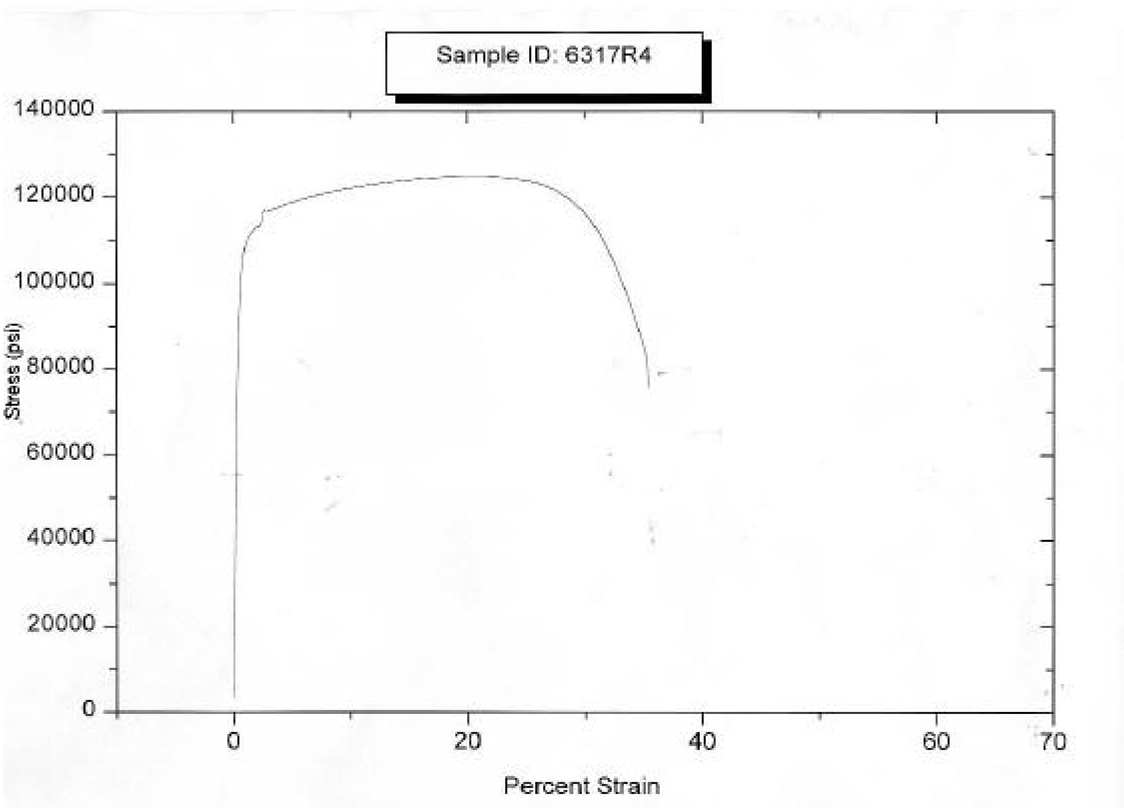


Figure 19. Average Stress-Strain Response of 304SS for the R5 Tensile Sample (Round IV)

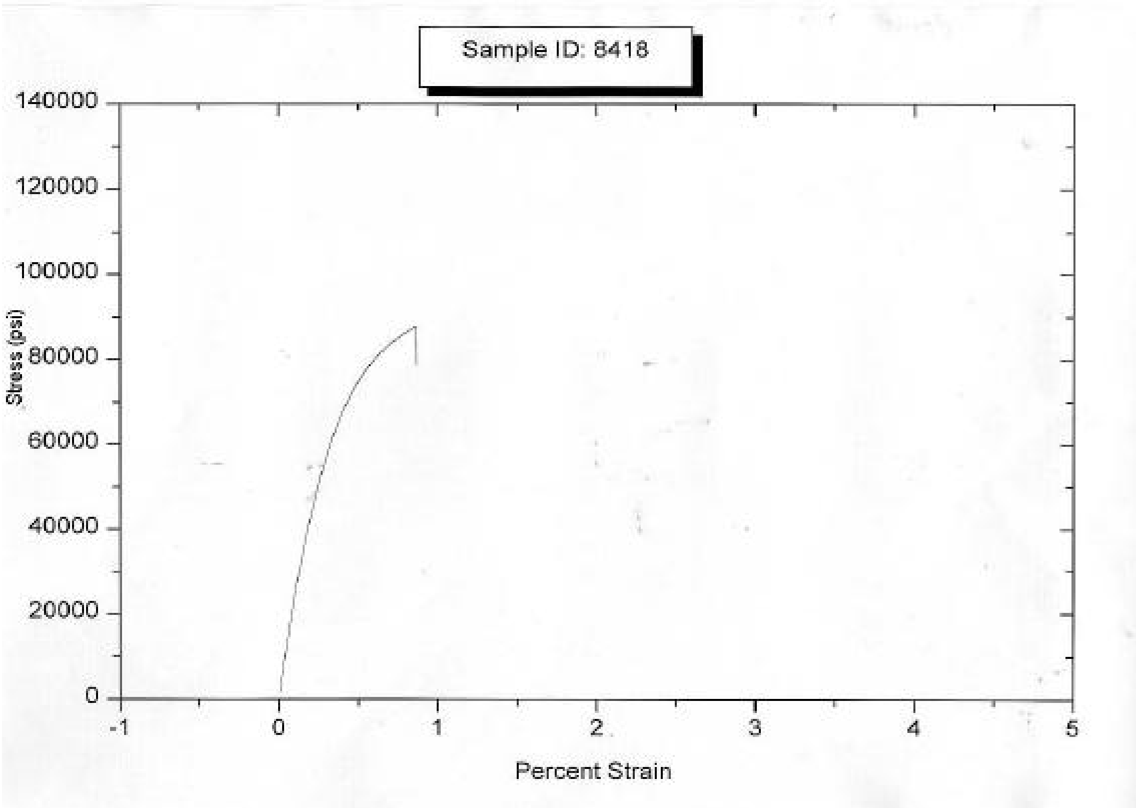


Figure 20. Average Stress-Strain Response of 304SS for the Miniature Compressive Sample (Round IV)

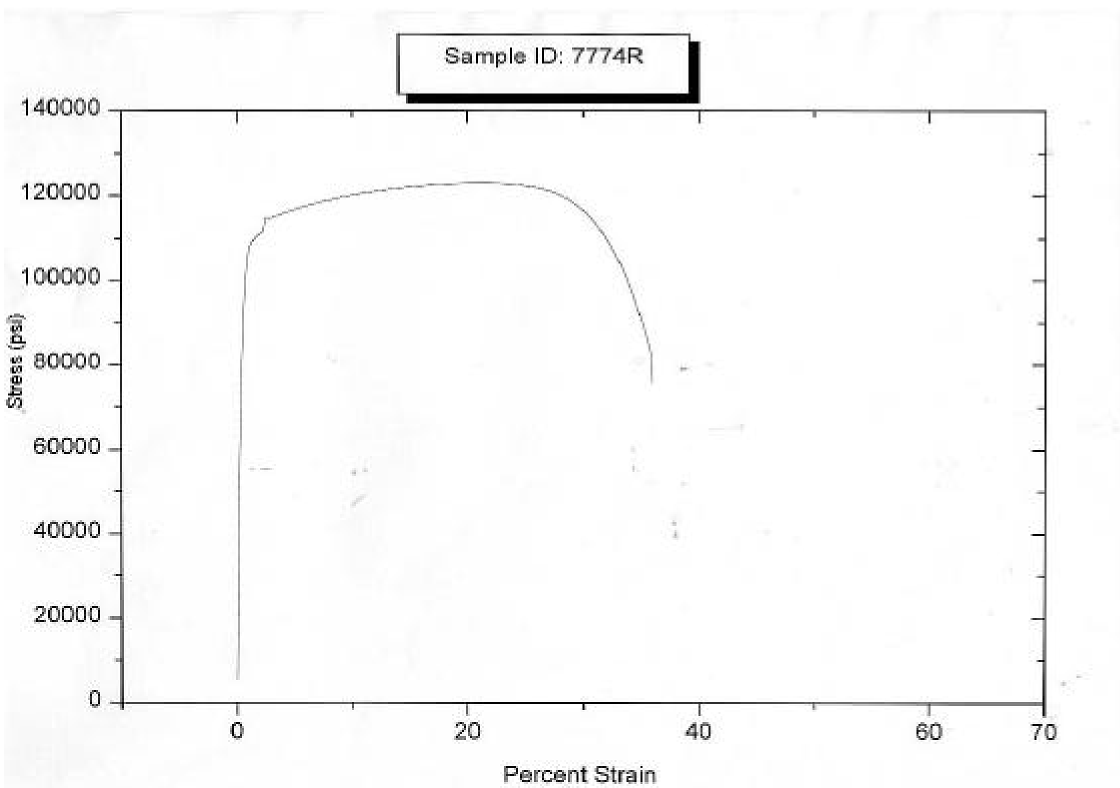


Figure 21. Average Stress-Strain Response of 304SS for the Miniature Tensile Sample (Round V)

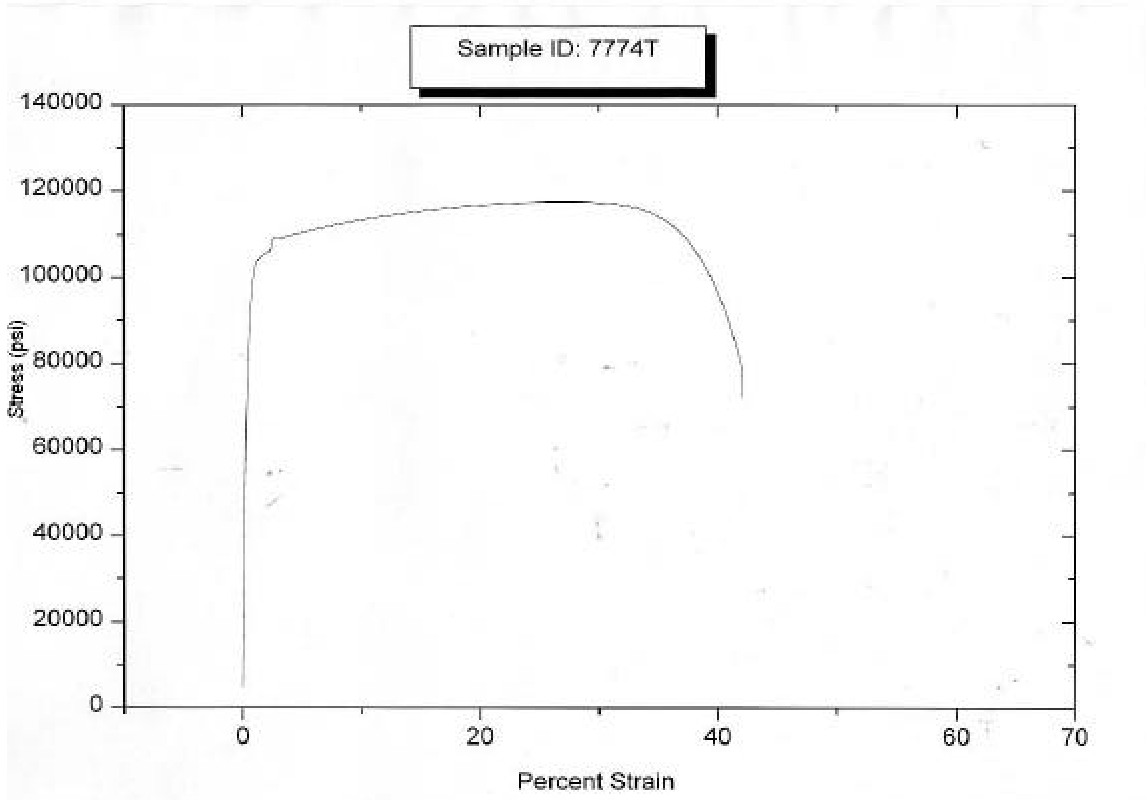


Figure 22. Average Stress-Strain Response of 304SS for the R5 Tensile Sample (Round V)

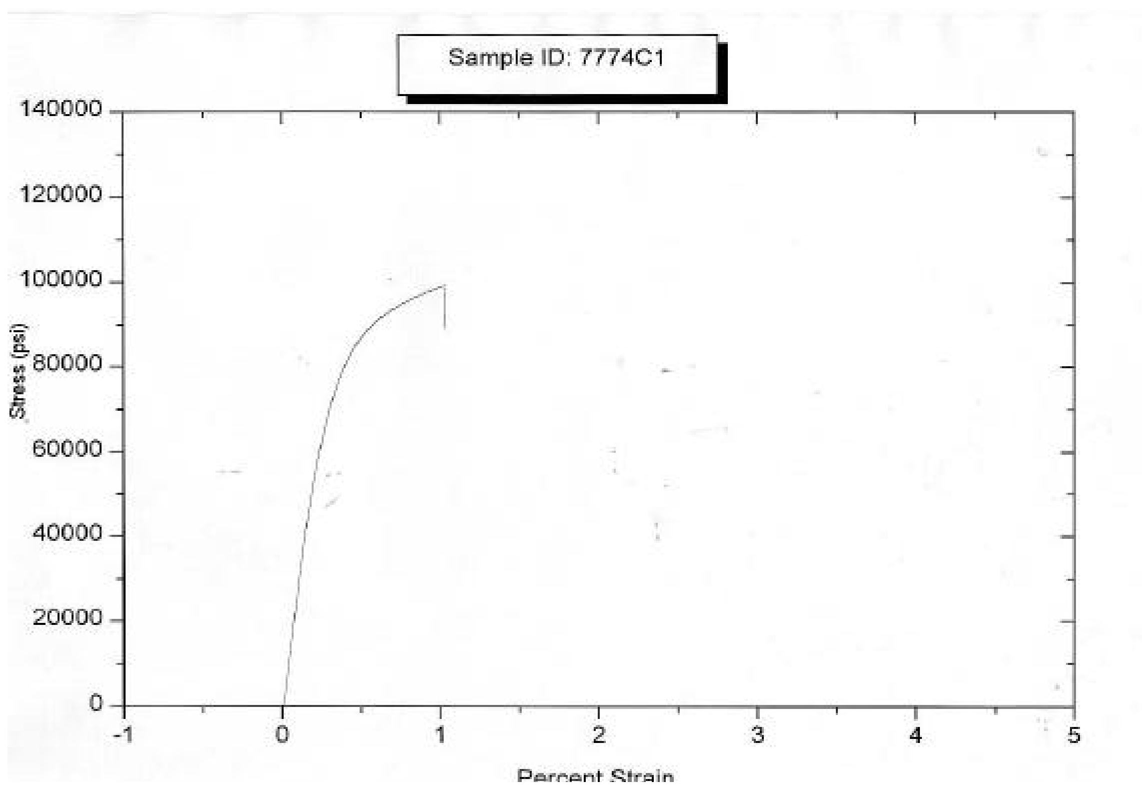


Figure 23. Average Stress-Strain Response of 304SS for the Miniature Compressive Sample (Round V)

Table 1. Mechanical Property Results for 304SS Using the Miniature Tensile Sample

(Round I)

S/N	Mod of Elasticity (msi)	0.2% Yield Strength (ksi)	Tensile Strength (ksi)	Elongation (percent)	Reduction of Area (percent)
1	29.2	53.8	95.1	54.8	81.7
2	30.4	54.3	95.9	53.9	80.8
3	29.1	54.3	95.8	53.7	81.3
4	29.6	53.7	95.8	54.0	80.8
5	30.8	53.0	95.7	53.6	81.8
6	28.0	53.8	94.1	56.0	80.9
7	31.4	53.6	95.9	53.6	82.0
8	29.5	54.0	96.0	53.4	79.6
9	28.4	54.8	96.1	53.0	81.8
10	28.3	52.6	95.2	53.7	81.1
Average	29.47	53.79	95.56	53.97	81.18
Std Deviation	1.12	0.64	0.61	0.85	0.71
Coeff of Var.	3.80	1.19	0.64	1.57	0.88

Table 2. Mechanical Property Results for 304SS Using the R3 Tensile Sample

(Round I)

S/N	Mod of Elasticity (msi)	0.2% Yield Strength (ksi)	Tensile Strength (ksi)	Elongation (percent)	Reduction of Area (percent)
1	26.3	51.8	104.2	59.8	83.5
2	29.6	52.6	105.0	50.8	75.6
3	30.3	53.9	102.0	65.5	85.3
4	31.9	49.4	102.1	61.9	79.2
5	25.1	48.9	102.0	59.0	84.0
6	34.8	44.0	100.8	64.1	80.3
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

7	27.3	49.3	101.1	53.8	81.2
8	23.5	51.6	102.1	62.5	86.0
9	33.5	48.1	105.1	57.4	82.3
Average	29.14	49.96	102.71	59.42	81.93
Std Deviation	3.87	2.95	1.63	4.81	3.27
Coeff of Var.	13.28	5.90	1.58	8.09	3.99

Table 3. Mechanical Property Results for 304SS

Using the Miniature Compressive Sample (Round I)

S/N	Mod of Elasticity (msi)	0.2% Yield Strength (ksi)
1	23.6	51.1
2	24.2	51.4
3	20.6	51.6
4	26.6	52.2
5	26.7	51.8
Average	24.33	51.61
Std Deviation	2.51	0.39
Coeff of Var.	10.32	0.76

Table 4. Mechanical Property Results for 304SS Using the Miniature Tensile

Sample (Round II)

S/N	Mod of Elasticity (msi)	0.2% Yield Strength (ksi)	Tensile Strength (ksi)	Elongation (percent)	Reduction of Area (percent)
1	31.8	52.9	95.6	57.5	85.6
2	29.9	53.7	96.4	58.0	86.0
3	27.0	54.5	97.8	54.3	82.0
4	33.3	54.2	97.2	55.8	80.8
5	34.9	53.2	96.2	56.6	85.8
6	30.0	54.2	96.7	57.5	84.0
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

7	30.3	54.6	96.9	56.1	81.0
8	30.8	53.4	96.5	57.2	82.9
9	26.4	53.9	96.9	56.0	84.2
10	25.9	54.5	97.5	55.9	84.7
Average	30.03	53.91	96.77	56.49	83.7
Std Deviation	2.94	0.59	0.64	1.10	1.94
Coeff of Var.	9.78	1.10	0.66	1.94	2.32

Table 5. Mechanical Property Results for 304SS Using the R3 Tensile Sample

(Round II)

S/N	Mod of Elasticity (msi)	0.2% Yield Strength (ksi)	Tensile Strength (ksi)	Elongation (percent)	Reduction of Area (percent)
1	40.3	48.4	102.4	50.7	87.9
2	43.0	46.4	105.3	58.7	88.8
3	37.8	46.8	101.5	57.7	89.3
4	27.5	44.3	100.8	60.4	88.5
5	42.3	47.7	102.4	52.9	89.7
6	49.9	48.1	102.6	54.7	90.1
7	41.3	46.4	105.1	57.0	87.5
8	47.7	43.3	101.4	59.0	88.1
9	22.5	46.2	101.5	57.0	86.9
10	41.2	45.9	100.5	54.4	89.6
Average	39.35	46.35	102.35	56.25	88.64
Std Deviation	8.42	1.60	1.65	3.02	1.04
Coeff of Var.	21.40	3.45	1.61	5.36	1.18

Table 6. Mechanical Property Results for 304SS

Using the Miniature Compressive Sample (Round II)

S/N	Mod of Elasticity (msi)	0.2% Yield Strength (ksi)
1	22.6	60.3
2	19.6	61.3

3	20.9	61.5
4	18.9	60.8
5	20.6	60.2
Average	20.51	60.81
Std Deviation	1.40	0.58
Coeff of Var.	6.84	0.96

Table 7. Mechanical Property Results for 304SS Using the Miniature Tensile Sample (Round III)

S/N	Mod of Elasticity (msi)	0.2% Yield Strength (ksi)	Tensile Strength (ksi)	Elongation (percent)	Reduction of Area (percent)
1	30.9	50.4	97.1	56.3	85.2
2	32.0	50.3	96.9	56.6	85.8
3	31.9	50.0	96.2	56.4	85.7
4	30.5	49.1	96.2	57.7	86.2
5	32.0	50.3	95.7	58.9	87.9
6	29.3	50.4	96.4	57.4	85.5
7	34.4	49.9	97.1	55.8	82.1
8	29.5	50.1	97.0	57.3	88.3
9	29.7	50.8	96.8	57.5	86.7
10	20.8	46.7	95.9	57.6	87.3
Average	30.1	49.8	96.53	57.15	86.07
Std Deviation	3.61	1.18	0.52	0.89	1.74
Coeff of Var.	12.00	2.36	0.54	1.56	2.02

Table 8. Mechanical Property Results for 304SS Using the R3 Tensile Sample (Round III)

S/N	Mod of Elasticity (msi)	0.2% Yield Strength (ksi)	Tensile Strength (ksi)	Elongation (percent)	Reduction of Area (percent)

1	27.9	49.1	102.1	55.8	87.3
2	33.7	48.7	102.6	50.2	87.5
3	28.8	51.8	103.1	53.6	87.3
4	30.3	44.6	102.0	59.5	85.6
5	31.3	47.5	102.8	56.3	85.0
6	28.1	48.5	101.0	62.8	85.0
7	30.7	53.6	104.5	51.8	89.2
8	29.5	52.7	105.3	48.0	78.9
9	29.3	51.1	102.4	59.2	89.9
10	33.3	48.6	102.5	50.2	86.5
Average	30.29	49.62	102.83	54.74	86.22
Std Deviation	2.01	2.70	1.24	4.80	3.04
Coeff of Var.	6.62	5.43	1.21	8.78	3.53

Table 9. Mechanical Property Results for 304SS

Using the Miniature Compressive Sample (Round III)

S/N	Mod of Elasticity (msi)	0.2% Yield Strength (ksi)
1	24.6	59.4
2	26.7	59.4
3	27.4	59.9
4	25.0	59.0
5	24.6	59.2
Average	25.68	59.38
Std Deviation	1.29	0.31
Coeff of Var.	5.01	0.52

Table 10. Mechanical Property Results for 304SS Using the Miniature Tensile

Sample (Round IV)

S/N	Mod of Elasticity (msi)	0.2% Yield Strength (ksi)	Tensile Strength (ksi)	Elongation (percent)	Reduction of Area (percent)

S/N	(msi)	(ksi)	(ksi)	(percent)	(percent)
1	26.6	95.0	125.0	38.6	84.9
2	30.5	89.0	125.0	35.5	83.9
3	27.6	91.7	124.0	36.6	84.4
4	27.0	92.8	125.0	36.2	85.6
5	27.9	95.6	125.0	37.8	82.0
6	28.1	93.5	124.0	36.8	85.1
7	25.5	96.6	126.0	40.4	84.4
8	25.6	92.3	126.0	37.8	83.1
9	29.4	92.9	124.0	39.2	85.9
10	28.1	95.7	124.0	38.2	84.6
Average	27.624	93.51	124.8	37.71	84.39
Std Deviation	1.56	2.28	0.79	1.48	1.16
Coeff of Var.	5.66	2.44	0.63	3.93	1.38

Table 11. Mechanical Property Results for 304SS Using the R5 Tensile Sample

(Round IV)

S/N	Mod of Elasticity (msi)	0.2% Yield Strength (ksi)	Tensile Strength (ksi)	Elongation (percent)	Reduction of Area (percent)
1	26.0	93.1	120.0	43.0	84.5
2	26.6	95.9	119.0	43.7	86.6
3	29.4	93.8	119.0	42.3	83.4
4	29.5	91.0	119.0	42.4	84.2
5	28.2	96.4	119.0	43.4	85.0
6	27.7	95.0	119.0	42.6	84.7
7	30.5	91.7	119.0	44.4	86.5
8	28.9	91.7	119.0	43.5	84.0
9	29.7	91.2	119.0	43.7	84.0
10	27.4	93.4	119	42.5	85
Average	28.39	93.32	119.10	43.15	84.79
Std Deviation	1.46	1.95	0.32	0.70	1.05
Coeff of Var.	5.13	2.09	0.27	1.62	1.24

Table 12. Mechanical Property Results for 304SS

Using the Miniature Compressive Sample (Round IV)

S/N	Mod of Elasticity (msi)	0.2% Yield Strength (ksi)
1	23.5	73.0
2	25.4	72.7
3	27.0	74.3
4	25.6	73.5
5	24.8	73.0
6	25.5	75.8
7	25.4	75.9
8	24.7	74.4
9	25.8	77.0
10	26.2	74.8
Average	25.39	74.44
Std Deviation	0.94	1.44
Coeff of Var.	3.68	1.94

Table 13. Mechanical Property Results for 304SS

Using the Miniature Tensile Sample (Round V)

S/N	Mod of Elasticity (msi)	0.2% Yield Strength (ksi)	Tensile Strength (ksi)	Elongation (percent)	Reduction of Area (percent)
1	30.1	86.2	123.0	36.8	86.6
2	25.7	90.5	124.0	37.3	86.5
3	26.9	87.0	124.0	35.2	81.5
4	31.9	86.6	123.0	38.8	85.4
5	30.7	87.2	123.0	37.0	85.3
6	26.3	87.2	122.0	41.8	86.3
7	27.8	85.5	123.0	39.2	86.5
8	25.5	87.9	123.0	39.9	85.5
9	26.9	88.3	123.0	40.4	86.8
10	28.2	86.0	122.0	40.4	84.6
Average	28	87.24	123	38.68	85.5

Std Deviation	2.21	1.43	0.67	2.05	1.58
Coeff of Var.	7.88	1.63	0.54	5.30	1.85

Table 14. Mechanical Property Results for 304SS Using the R5 Tensile Sample

(Round V)

S/N	Mod of Elasticity (msi)	0.2% Yield Strength (ksi)	Tensile Strength (ksi)	Elongation (percent)	Reduction of Area (percent)
1	24.4	87.3	118.0	44.0	84.5
2	29.0	83.8	118.0	44.8	84.6
3	25.7	86.2	118.0	43.9	82.4
4	25.3	86.0	118.0	43.6	85.6
5	26.7	84.1	117.0	45.6	85.5
6	24.8	87.5	118.0	42.0	84.1
7	25.7	86.4	118.0	45.9	85.2
8	25.0	85.5	117.0	43.4	85.4
9	24.9	87.3	118.0	43.0	84.4
10	26.5	86	117	43.7	84.6
Average	25.80	86.01	117.70	43.99	84.63
Std Deviation	1.34	1.27	0.48	1.18	0.94
Coeff of Var.	5.20	1.48	0.41	2.67	1.11

Table 15. Mechanical Property Results for 304SS

Using the Miniature Compressive Sample (Round V)

S/N	Mod of Elasticity (msi)	0.2% Yield Strength (ksi)
1	29.9	87.1
2	32.7	86.0
3	36.9	86.0
4	33.0	86.0
5	27.3	85.5
6	32.6	88.6
7	31.3	83.4

8	27.8	87.6
9	28.3	85.9
10	31.7	87.9
Average	31.15	86.40
Std Deviation	2.93	1.47
Coeff of Var.	9.39	1.71

Table 16. Average Mechanical Properties Results for All Test Rounds

Modulus of Elasticity (x 10^6 psi)

Sample Configuration	Round I	Round II	Round III	Round IV	R
Micro-Tensile	29.5	30.0	30.1	27.6	
R3/R5 Tensile	29.1	39.4	30.3	28.4	
Micro-Compression	24.3	20.5	25.7	25.4	
% Difference from R# Result (Tensile)	1.13	-23.68	-0.63	-2.71	
% Difference from R# Result (Compression)	-16.51	-47.88	-15.22	-10.57	

Average Tensile Strength (x10^3 psi)

Sample Configuration	Round I	Round II	Round III	Round IV	R
Micro-Tensile	95.6	96.8	96.5	124.8	
R3/R5 Tensile	102.7	102.4	102.8	119.1	
% Difference from R# Result	-6.96	-5.45	-6.13	4.79	

0.2% Yield Strength (x10^3 psi)

Sample Configuration	Round I	Round II	Round III	Round IV	R
Micro-Tensile	53.8	53.8	49.8	93.5	
R5 Tensile	50.0	50.0	49.6	93.3	
Micro-Compression	51.6	51.6	59.4	74.4	
% Difference from R# Result (Tensile)	7.67	7.67	0.36	0.20	
% Difference from R# Result (Compression)	3.30	3.30	19.67	-20.23	

Elongation (percentage)

Sample Configuration	Round I	Round II	Round III	Round IV	R
Micro-Tensile	54.0	56.5	57.2	37.7	
R3/R5 Tensile	59.4	56.3	54.7	43.2	
% Difference from R# Result	-9.17	0.43	4.40	-12.61	-

Reduction of Area (percentage)

Sample Configuration	Round I	Round II	Round III	Round IV	R
Micro-Tensile	81.2	83.7	86.1	84.4	
R3/R5 Tensile	81.9	88.6	86.2	84.8	
% Difference from R# Result	-0.92	-5.57	-0.17	-0.46	

References

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