

Mechanical Property Changes in Steel during the Pipe Making Process

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Abstract

Welded Steel Pipe (WSP) is arguably the most widely utilized pipe material for the transmission of water throughout the United States. Spiral WSP is manufactured by placing steel coils, supplied by steel mills to the pipe manufacturer, into a pipe mill that levels the coils and helically rolls and welds the steel sheet into pipe. During the pipe manufacturing process, the steel undergoes various permanent changes in shape. These changes require the steel to yield, which may result in alterations to the mechanical properties of the original steel coil. The pipe ends may also be expanded past yield point or swaged to shape a bell, while spigot ends may be rolled to accommodate gaskets. All of this processing can have varying effects on the steel's mechanical properties. While various factors of safety incorporated into the design of steel pipe systems amply address any potential mechanical property changes that may take place during fabrication of the pipe, the topic has never been fully understood by the design engineering community at large. In order to address this issue, testing was done to measure the changes in steel mechanical properties during the pipe manufacturing process. This paper outlines the testing and the subsequent variations found in the mechanical properties of the steel used through the manufacturing process. Based on the testing, the paper will provide conclusions and design considerations for pipe with both restrained (welded) and non-restrained joints.

Introduction

It is well understood that cold working steel will change its mechanical properties. The amount of change that can occur is dependant on the amount of work done to the steel. The actual amount of change that can be expected when forming steel pipe has been explored and studied in the oil and gas steel pipe market, but not much work on the subject has been completed in the water pipe market. Although the testing for the Pipeline Research Council International by Battelle Memorial Institute (Maxey 1988) as well as research done by Shoemaker (1984) showed no impact to the function or design of the pipe, the research that had been completed on pipe was manufactured by the U-ing and O-ing processes (See Figure 1) to oil and gas pipe standards.

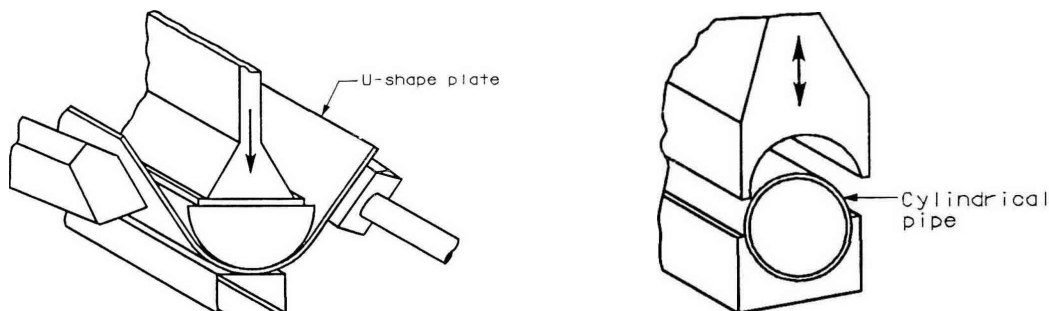


Figure 1 U-ing and O-ing Pipe Making Process

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There has been interest and misunderstanding in the steel water pipe marketplace regarding the actual amount of change that can occur in the steel in a typical manufacturing process. There are differences in steel water pipe manufacturing when compared to oil and gas pipe in that it is typically made by helically shaping steel from coil. Additional steps are often used to form a bell and spigot in the steel pipe for water applications that oil and gas pipe would not typically see. Because of the different characteristic of the steel typically used in oil and gas pipe, the different forming process used and the added steps typical in the water industry, questions have been raised about the potential mechanical property changes and its impact on the steel pipe's performance over time.

To address questions regarding the effects of cold forming during the typical steel water pipe manufacturing process, testing was conducted to determine mechanical changes found in the steel. Tests were completed on three different pipe sections. One pipe sample was from 84" nominal diameter, 0.625" wall thickness with a weld bell joint (325 psi design operating pressure), and the other two were 30" nominal diameter rolled groove gasket joint pipes one 0.149" (165 psi design operating pressure) and one 0.215" (300 psi design operating pressure) thickness. The three pipes were manufactured to AWWA C200 standards using the spiral forming method. Testing conducted on all of the samples were Charpy impact, yield strength, ultimate tensile strength, elongation, hardness, and grain structure.

Pipe Manufacturing Process

The most commonly used pipe manufacturing method for steel water pipe is spiral welding coil steel in a continuous process (See Figure 2). The process starts with steel coils placed in the pipe mill and the material unrolled off the coil and leveled. The edges of the coil are trimmed or machined for welding and the steel is fed through forming rolls at a set helix angle. The feed angle and the width of the coil determine the diameter of the pipe. The pipe is formed and welded in a continuous operation and typically joined with submerged arc welding, with a weld on the inside of the pipe and one on the outside. The pipe sections are then cut at the desired length.

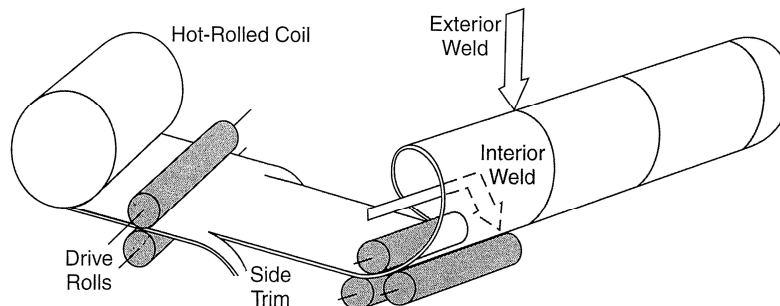


Figure 2 Spiral Pipe Manufacturing

Once the pipe barrel is formed, the ends are formed to accommodate connections to other pipe sections during installation. The bell end typically is formed by

hydraulically expanding the pipe end with a segmented die. Another common method entails the bell being formed by pushing the pipe end over a die, taking the steel past yield point, which is sometimes called swaging. With swaging, the desired bell shape and size are determined by the die. For a weld bell joint, the pipe end is typically expanded to increase the diameter by twice the steel thickness, to allow for engagement of the mating spigot (see Figure 3). Bells formed for gasket joints are typically swaged or expanded further than weld bell joint to accommodate the gasket retaining system without reducing the inside diameter of the pipe at the spigot end (see Figure 4).



Figure 3 Typical Weld Bell Joint



Figure 4 Typical Rolled Groove Gasket Joint

If the pipe is a rolled groove gasketed pipe, the next step is to roll the spigot shape that holds the gasket in place. This is done by rolling the spigot end of pipe through shaped dies.

It can be readily seen that all of these processes cold work the steel to one degree or another.

Testing Procedures

Samples were gathered from 0.625", 0.207" and 0.149" thick material. For the weld bell pipe, samples were taken from the coil before fabrication, from the pipe body after forming, and from the bell after expansion. The bell was expanded using a hydraulic segmented expander.

The rolled groove gasketed pipe had samples taken from the pipe body, the expanded bell and from the formed gasket section on the spigot. The expanded bells on the gasketed pipe were formed by the swedge method. The samples were cut from the specific areas and each sample tested for the following:

1. Charpy v-notch testing per ASTM A370-09a Standard Test Methods and Definitions for Mechanical Testing of Steel Products.
2. Rockwell hardness "B" testing per ASTM E18-08b Standard Test Methods for Rockwell Hardness of Metallic Materials
3. Grain size per ASTM E112-96 Standard Test Methods for Determining Average Grain Size
4. Yield point per ASTM A370-09a Standard Test Methods and Definitions for Mechanical Testing of Steel Products

5. Ultimate tensile strength per ASTM A370-09a Standard Test Methods and Definitions for Mechanical Testing of Steel Products
6. Elongation per ASTM A370-09a Standard Test Methods and Definitions for Mechanical Testing of Steel Products

Yield point was determined by using the 0.2% offset method in accordance with ASTM A370. Elongation was determined by using the 2 inch gage length for the 0.149” and 0.207” thickness materials. The 0.625” material elongation was tested using the bar method, giving equivalent results to a 2 inch gage, as prescribed in ASTM A370.

Rockwell hardness tests were reported as method “B” as described in ASTM E18 for all samples.

Grain size was measured using 200X magnification using ASTM A112.

Charpy test temperatures for all samples was 30 Deg F. Full size samples were tested for the 0.625” thickness material and subsize samples were required for the 0.207” and 0.149” thickness materials as detailed in ASTM A370.

Tested Materials

The three steel chemistries are representative of some of the most common grades of steel used in steel water pipe in the United States. The materials tested were as follows:

1. 0.625” thickness coil manufactured in accordance with ASTM A 1018, Grade 45, Class 1, high strength low alloy steel (HSLAS).
2. 0.207” thickness coil manufactured in accordance with ASTM 1011, Grade 45, structural steel (SS).
3. 0.149” thickness coil manufactured in accordance with ASTM 1011, Grade 36, Type 1, structural steel (SS).

The ASTM minimum required yield, tensile and elongation for the steel grades tested can be found in table 1.

Grade	Thickness	Yield	Tensile	Elongation 2"
1018 Gr 45 C11	0.625	45,000	60,000	22
1011 Gr 45 SS	0.207	45,000	60,000	19
1011 Gr 36 Type 1	0.149	36,000	53,000	22

Table 1 ASTM Minimum Requirements for Tested Grades of Steel

All materials were ordered in accordance with the listed ASTM standard as well as the additional requirements of AWWA C200. Additionally, AWWA C200 requires steel to be fully killed, and manufactured to a fine grain practice. ASTM defines fine grained to have a grain size number of 5 or greater as determined by ASTM E112.

The pipe, bells, and spigots were formed and fabricated in accordance with AWWA C200. AWWA C200 further requires the ordered yield, tensile, and elongation properties of the steel are minimum values. As such, the actual values seen from steel mills tend to be considerably higher than those ordered because the steel mills must certify the material does not drop below those minimum values. Because steel pipe designed to the AWWA standards is based on the minimum ordered yield strength of the steel, the additional level of mechanical properties provided from the steel mill gives safety factors that are not utilized during pipe design, giving steel pipe an additional level of conservatism in its application.

The level of cold work applied to the steel for typical pipe can be expected to increase depending on the joint configuration. The lowest expected level of cold working is found in straight pipe with no joint preparation completed. Next is the expanded weld bell end followed by the swaged or expanded gasket bell end and the rolled groove getting the most cold work of the joints tested. The gasket bell typically receives more cold work than a weld bell because it must be expanded further than a weld bell to accommodate the rolled shape of the spigot.

Sample Preparation

Samples were flame cut from the coil, pipe barrel and pipe bell and spigot. Each sample was identified for traceability by a sample number, coil number and location from where they were removed. Figure 5 shows a typical sample with it's identification before removal from a pipe section.

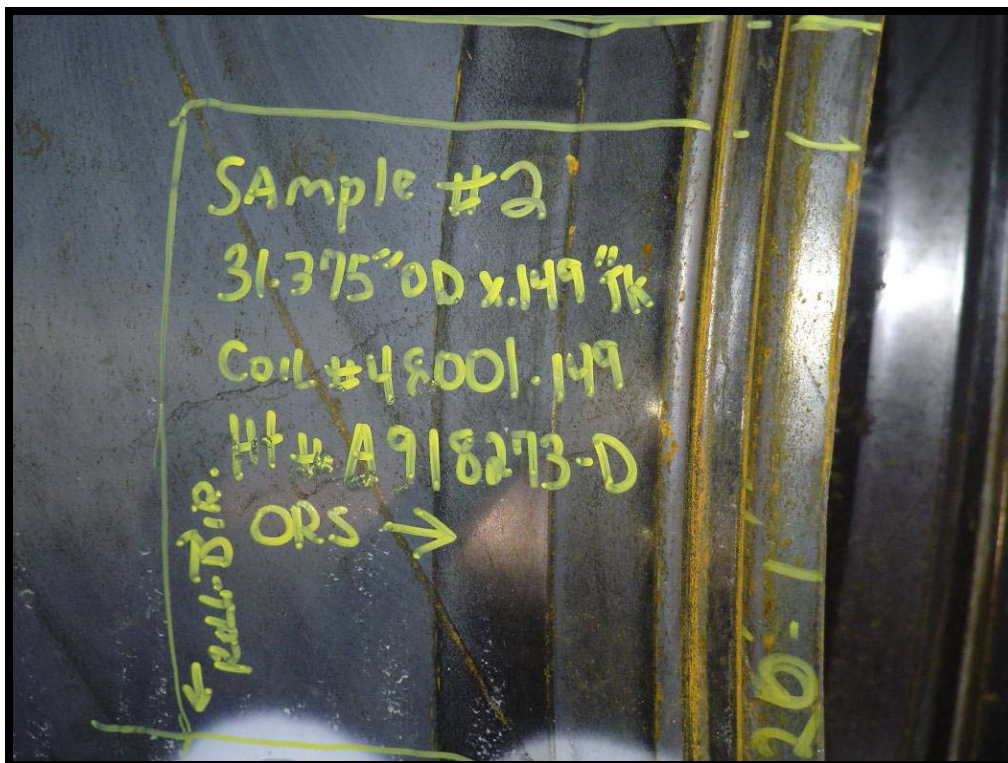


Figure 5 Typical Sample Layout and Marking (Rolled Groove Spigot)

Figure 6 shows the removal of a sample from the pipe. Once the samples were removed from the pipe they were submitted to an independent testing lab for evaluation. All testing was completed by IMR KHA of Portland Oregon, an ISO/IEC 17025 certified lab. Samples were prepared in accordance with the applicable ASTM standards for the tests listed.



Figure 6 Typical Sample Removals

Samples in the pipe body were taken both in the steel rolling direction as well as in the pipe hoop direction in the 0.149” and 0.207” samples. Samples from the pipe bells were taken in the flat of the bell (the area of engagement with the mating pipe). Rolled groove samples were taken to include the rolled shape of the spigot and the test samples were all prepared in a manner to include the worked steel in the results.

It should be noted, the samples from the rolled groove area required additional preparation beyond that of the other samples, Figure 7 shows the rolled groove shape. It was necessary to flatten the rolled shape before testing. For the yield / tensile samples a section had to be welded on to the end of the sample to get the formed end inside the tested area. The step of flattening added an additional step of cold working that would not be seen in actual application.



Figure 7 Typical Rolled Groove Shape

Testing Results

Tables 2, 3 and 4 give the test results from each of the samples. The data was tabulated, each test location values were averaged and all the values from each thickness of material were averaged and a standard deviation was calculated.

For the Charpy results (CVN) the actual result is listed (CVN AVG) and the sample size is listed. Standard full size Charpy samples are 10 mm by 10 mm, if the material being sampled is below that thickness, subsize samples are tested. The 0.149” required 10 mm by 2.5 mm or ¼ size samples and 0.207” required 10 mm by 5 mm or ½ size samples. Although a direct meaningful correlation of subsize to full size values is difficult to make, an approximation can be made based on ASTM A370. The approximation is made by simply dividing the subsize Charpy value by its corresponding size. For example a ½ size sample that achieved 15 ft-lbs would have a corrected value of 30 ft-lbs. The approximations for the subsize samples tested are listed as CVN Corrected For Subsize in Tables 3 and 4.

Figures 8 and 9 show micrograph photos of 0.149” samples magnified 200X. The samples were taken from the pipe body and the rolled spigot. It can be seen that there is no discernable change in the grain structure of the steel.

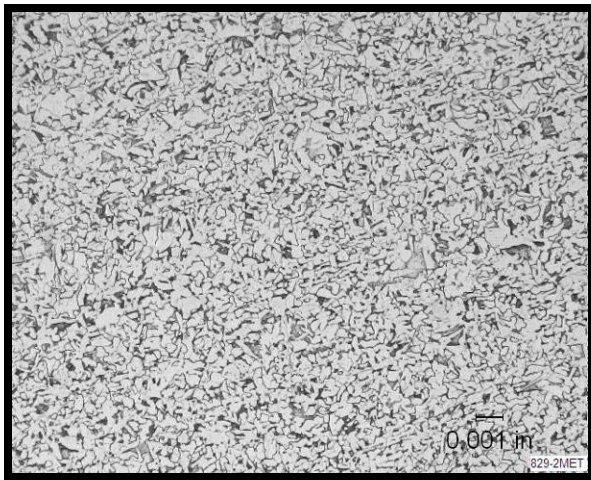


Figure 8 0.149” Pipe Body Sample

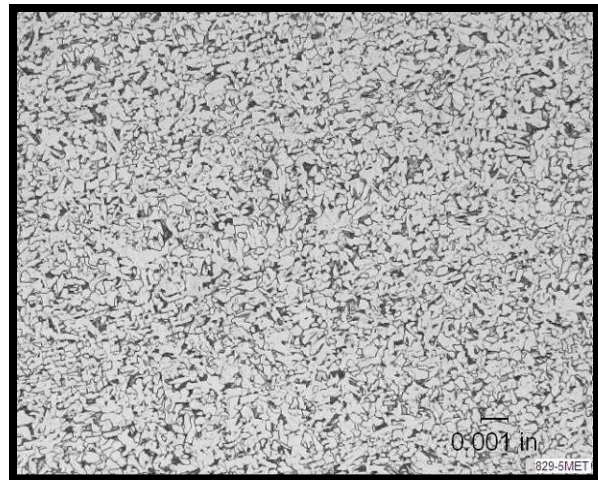


Figure 9 0.149” Rolled Groove Sample

Conclusions

The test results after cold forming of pipe barrel, expanded bells and rolled spigots show that the as manufactured steel properties demonstrate no discernable reduction in steel properties and that the as tested steel properties are far greater than those required by AWWA standards.

The testing data does demonstrate some minor variability in the results, particularly in the yield strength of the steel. It is unclear if the variability in the testing results is due to the natural properties of the steel as supplied from the steel mill or if there was some change induced from the pipe making process. It is well known that cold working steel will increase the tensile-yield strength, and therefore some of the minor changes seen are likely attributed to the cold working.

The changes in yield strength are insignificant in typical water pipe applications, first because the amount of possible change seen in the testing would be considered normal variance in properties as received from the steel mills. Second, the change in yield strength from cold working will be an increase, not a decrease, adding to the design safety factor of the pipeline. Ultimately the amount of variation seen in the tests is negligible in pipe applications.

There were no discernable changes in the Charpy, Rockwell hardness, ultimate tensile, elongation, or grain structure properties tested. The results were within the expected accuracy of the tests completed. It should be noted that there is some amount of variance expected simply from the test process itself. For example, in Charpy testing, variability of a few ft-lbs is considered normal due to the changes that can come from the testing process. Slight variations in the radius preparation of the notch placed in the steel, the thickness variation of the sample, variations in temperature of the sample at time of impact, the placement of the sample in the testing apparatus. All of these variables have allowable tolerances in the ASTM standard and they can have mirror effects on the test values. Variations of a few ft-lbs are not uncommon in Charpy results. It is one of the key reasons that ASTM methods require that three samples are averaged to create one net Charpy test resultant. This type of variation can be easily misinterpreted when the Charpy values are particularly low. A 2 or 3 ft-lb variance in samples breaking at 10 or 11 ft-lbs force looks much more significant than the same variance at 50 or 100 ft-lbs.

It was thought the rolled groove spigot would show the greatest variances since it not only underwent the most cold working in forming the shape, but it was worked again to flatten the sample for testing. The testing results did not reflect this assumption. The test results show that the steel tested is capable of being rolled and flattened without significant changes to the mechanical properties of the steel.

Based on the results of the testing, mechanical properties of steel during typical pipe manufacturing processes used for pipe manufactured to AWWA C200 do not change in any significant way. Further, design safety factors applied to steel water pipe are not reduced by the pipe manufacturing process. Steels used in the testing show that they are capable of handling the cold work applied during the manufacturing process of AWWA C200 steel water pipe without degradation of their mechanical properties from pipe making or joint formation. The testing confirms there is no need to limit hoop stress or axial load design for unrestrained rolled groove or restrained weld bell joints.

Table 2 Test Results for 0.625” thickness 84” Diameter Weld Bell Pipe

Thickness in.	Diameter in.	Sample Location	Yield psi (Y)	Tensile psi (T)	T-Y	Y/T	Elongation	CVN AVG Ft-lbs	CVN Size mm	Sub-size	CVN Corrected For Sub-size	Rockwell B Avg	Grain Size
0.625	84	Coil	52200	65700	13500	0.79	32.0	262.5 ¹	10	N	NA	75.0	8.0
0.625	84	Coil	53200	65900	12700	0.81	32.5	262.5 ¹	10	N	NA	77.0	10.0
0.625	84	Coil	56200	66500	10300	0.85	31.5	262.5 ¹	10	N	NA	77.0	9.5
		Average	53867	66033	12167	0.82	32.0	262.5				76.3	9.2
0.625	84	Pipe Body	54300	66700	12400	0.81	34.0	262.5 ¹	10	N	NA	77.5	9.5
0.625	84	Pipe Body	54000	67000	13000	0.81	32.0	262.5 ¹	10	N	NA	77.5	9.5
0.625	84	Pipe Body	53500	67200	13700	0.80	31.0	262.5 ¹	10	N	NA	77.5	9.5
		Average	53933	66967	13033	0.81	32.3	262.5				77.5	9.5
0.625	84	Weld Bell	53300	67000	13700	0.80	30.5	262.5 ¹	10	N	NA	77.5	9.0
0.625	84	Weld Bell	54500	67200	12700	0.81	32.0	262.5 ¹	10	N	NA	79.0	9.5
0.625	84	Weld Bell	53400	66700	13300	0.80	31.0	262.5 ¹	10	N	NA	79.5	9.5
		Average	53733	66967	13233	0.80	31.2	262.5				78.7	9.3
		0.625 Mean	53844	66656	12811	0.81	31.8	262.5				77.5	9.3
		Standard Dev.	1051	510	990	0.01	1.0	0.0				1.2	0.5

Note 1. Machine capacity was exceeded on 0.625” CVN tests and the samples did not break, max machine value is listed.

Table 3 Test Results for 0.207” thickness 30” Diameter Gasket Bell Pipe

Thickness in.	Diameter in.	Sample Location	Yield psi (Y)	Tensile psi (T)	T-Y	Y/T	Elongation	CVN AVG Ft-lbs	CVN Size mm	Sub-size	CVN Corrected For Sub-size	Rockwell B Avg	Grain Size
0.207	30	Pipe Body	56400	75900	19500	0.74	29.0	37.8	5	Y	75.7	80.5	10.5
0.207	30	Pipe Body	54300	76200	21900	0.71	28.0	37.0	5	Y	74.0	82.0	10.5
		Average	55350	76050	20700	0.73	28.5	37.4				81.3	10.5
0.207	30	Pipe Body Hoop	53200	76200	23000	0.70	29.5	40.0	5	Y	80.0	83.5	10.5
0.207	30	Pipe Body Hoop	55000	75800	20800	0.73	27.0	40.0	5	Y	80.0	81.5	10.5
		Average	54100	76000	21900	0.71	28.3	40.0				82.5	10.5
0.207	30	Gasket Bell	56200	76100	19900	0.74	28.0	39.2	5	Y	78.3	83.5	10.5
0.207	30	Gasket Bell	50300	76300	26000	0.66	28.5	41.2	5	Y	82.3	84.0	10.5
		Average	53250	76200	22950	0.70	28.3	40.2				83.8	10.5
0.207	30	Rolled Spigot	54800	74700	19900	0.73	26.5	40.2	5	Y	80.3	81.5	10.5
0.207	30	Rolled Spigot	50900	75900	25000	0.67	28.0	39.5	5	Y	79.0	80.0	10.5
		Average	52850	75300	22450	0.70	27.3	39.8				80.8	10.5
		0.207 Mean	53888	75888	22000	0.71	28.1	39.0				82.1	10.5
		Standard Dev	2126	478	2305	0.03	0.9	2.6				1.4	0

Table 4 Test Results for 0.149” thickness 30” Diameter Gasket Bell Pipe

Thickness in.	Diameter in.	Sample Location	Yield psi (Y)	Tensile psi (T)	T-Y	Y/T	Elongation	CVN AVG Ft-lbs	CVN Size mm	Sub-size	CVN Corrected For Sub-size	Rockwell B Avg	Grain Size
0.149	30	Pipe Body	50400	72100	21700	0.70	29.0	12.0	2.5	Y	48.0	81.0	10.5
0.149	30	Pipe Body	53800	72900	19100	0.74	28.0	13.7	2.5	Y	54.7	80.0	10.5
		Average	52100	72500	20400	0.72	28.5	12.8				80.5	10.5
0.149	30	Pipe Body Hoop	52900	71800	18900	0.74	29.0	11.2	2.5	Y	44.7	80.0	10.5
0.149	30	Pipe Body Hoop	52800	73300	20500	0.72	30.0	14.0	2.5	Y	56.0	82.0	10.5
		Average	52850	72550	19700	0.73	29.5	12.6				81.0	10.5
0.149	30	Gasket Bell	55400	73000	17600	0.76	30.5	13.3	2.5	Y	53.3	81.5	10.5
0.149	30	Gasket Bell	58600	76400	17800	0.77	24.0	13.7	2.5	Y	54.7	86.5	10.5
		Average	57000	74700	17700	0.76	27.3	13.5				84.0	10.5
0.149	30	Rolled Spigot	54500	72900	18400	0.75	28.5	13.5	2.5	Y	54.0	80.0	10.5
0.149	30	Rolled Spigot	53500	72800	19300	0.73	29.0	13.7	2.5	Y	54.7	80.5	10.5
		Average	54000	72850	18850	0.74	28.8	13.6				80.3	10.5
		0.149 Mean	53988	73150	19163	0.74	28.5	13.1				81.4	10.5
		Standard Dev.	2216	1312	1284	0.02	1.9	0.9				2.0	0

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