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# **Joint Efficiency Factors for A.O. Smith Line Pipe**

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## **INTRODUCTION**

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Many US pipeline operators are performing extensive review of their records and field verification of listed pipe segments in order to validate segment maximum allowable operating pressure (MAOP). To further this work, operators need a complete understanding of the longitudinal seam design factor for pipe in service. Some pipeline operators' system inventory includes pipe manufactured by the A.O. Smith Company (AOS). AOS used unique seam manufacturing processes at specific times in its history. This report recommends a Joint Efficiency Factor for specific seam types used by AOS in manufacturing pipe.

## **SUMMARY AND CONCLUSIONS**

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Four distinct seam types are associated with pipe manufactured by A.O. Smith: early single shielded metal arc welded (SMAW) seams from 1927 to 1930, electric flash welded (FW) seams having a SMAW cover pass starting in 1930 until around 1940, flash welded seams post-1930 (possibly not prior to 1940) until 1969, and double-submerged arc welded (DSAW) seams made from 1965 until 1973. Joint efficiency factors appropriate to each type of AOS seam, based on provisions in the ASA or ASME B31 Code and considering what is known about AOS pipe manufacturing practices, are listed in Table 1.

AOS introduced significant advancements to pipe manufacturing, including the cold expansion process and hydrostatic testing to 90% of the specified minimum yield strength (SMYS). The pressure testing requirements exceeded minimum requirements

of pipe product specifications for many years. These manufacturing steps enabled AOS pipe, particularly those with flash-welded seams, to exhibit seam reliability as good as or better than pipe of the era manufactured with other types of seams. AOS also produced pipe having higher material strength than many contemporaneous standard grade strength requirements.

**Table 1. Recommended Joint Efficiency Factors for AOS Line Pipe**

<b>Years Made</b>	<b>Seam Type</b>	<b>Pipe Length, ft</b>	<b>Joint Factor, E</b>
1927-1930	SMAW	30	0.80
1930-1940(?)	FW+SMAW cap	40	0.85
1930(?)-1969	FW	40	1.00
1965-1973	DSAW	40	1.00

## **LINE PIPE MANUFACTURED BY A.O. SMITH**

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### **Brief History of the A.O. Smith Company**

The A.O. Smith Company began manufacturing parts for carriages and then bicycles in 1874. By the early 20<sup>th</sup> Century, the company had become a major supplier of steel components to many industries. During World War I, as a major armaments supplier, AOS developed expertise in fabrication by welding. Seeking opportunities to apply its knowledge of welding after the war, the company began manufacturing pressure vessels. In 1918 the company developed the first coated welding electrode,<sup>1</sup> and in 1925 produced a cellulosic electrode that was essentially what later became identified as the E6010 electrode, and which has been widely used in the industry.<sup>2</sup>

AOS provided pipe and field welding services to early welded gas pipeline construction projects between 1927 and 1929, including the Magnolia Gas pipeline, the Uinta Gas pipeline (1929), and two gas pipelines from Kettleman Hills (one for PG&E and the other for Southern California Gas).<sup>3</sup> AOS introduced the bell-bell-chill-ring (BBCR) joint to these projects in order to facilitate the use of an internal backing ring that did not protrude into the product stream inside the pipe.

<sup>1</sup> [www.aosmith.com/About/](http://www.aosmith.com/About/)

<sup>2</sup> Barkow, A.G., "History of Pipe Line Welding – Part I", Welding Journal, Nov. 1977.

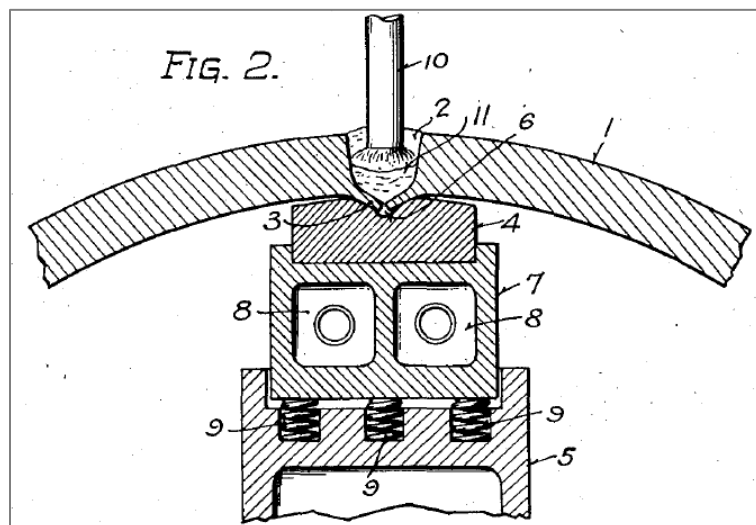
<sup>3</sup> Graham, W.T., "Pipe Line Welding", Natural Gas, Nov. 1930.

In 1927, AOS began producing line pipe from plate with the longitudinal seam made by manual or automated single-sided shielded-metal arc welding.<sup>4,5</sup> AOS soon determined that the SMAW process was too slow to keep up with demand. The flash welding process was already in use for manufacturing other industrial products so AOS applied it to pipemaking starting in 1930. The details of these seam types and of AOS's pipe manufacturing process as they pertain to line pipe properties and quality are discussed subsequently. AOS produced flash welded line pipe or casing tubular goods in Milwaukee from 1930 until 1971, and in Houston from 1950 until 1969. The Houston mill was converted to DSAW in 1969, and ceased production in 1973.<sup>6</sup>

## Seam Manufacturing Methods Used by A.O. Smith

### Early Seams

AOS produced pipe using a manual or automatic single sided SMAW process in 1927. The weld metal was deposited in a wide U-shaped groove. Prior to welding, the pipe edges at the groove were pressed together so as to cause the lower part of the groove to deform toward the pipe interior into a recess in a backing bar to contain the weld root. The configuration of the welding arrangement is shown in Figure 1.<sup>7</sup>



**Figure 1. Patent Detail of Welding into Groove over Grooved Chill Bar**

<sup>4</sup> Clark, E.B., El Paso Natural Gas, memorandum to Kiefner, J.F., KAI, 03/19/96, source unattributed.

<sup>5</sup> Lazor, R., Interprovincial Pipe Line Co., memorandum to Maxey, W.A., KAI, 07/25/95, source unattributed.

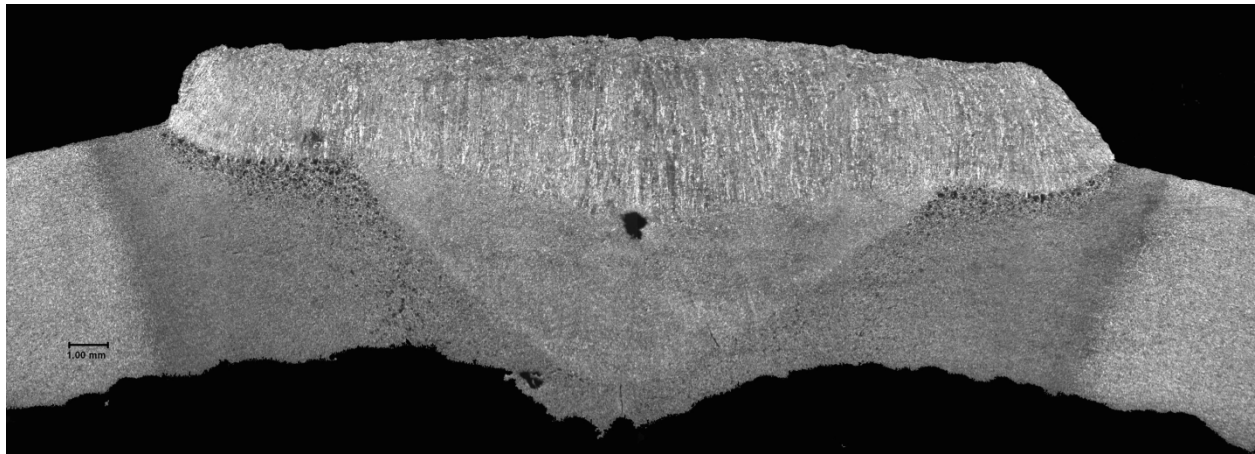
<sup>6</sup> Kiefner, J.F., and Clark, E.B., "History of Line Pipe Manufacturing in North America", CRTD-Vol. 43, ASME, 1996.

<sup>7</sup> Priebe, A.W. and A.O. Smith Company, "Arc Welding Chill", US Patent No. 1,844,263, Issued Feb. 9, 1932.

This arrangement produced a seam having a typical appearance in cross section as shown in Figure 2 and Figure 3.<sup>8</sup> The resulting weld bead had a cap approximately 1 inch wide and 1/8 inch thick (more or less) with a characteristic external appearance as shown in Figure 4 and Figure 5. Figure 4 shows the seam terminating at a girth weld produced using acetylene welding.

Single SMAW seams generally possessed good strength and adequate quality. The example seams shown in Figure 2 and Figure 3 exhibit minor porosity, and possible lack of fusion where the plate edges were pressed together at the bottom of the welding groove. The effect of welding defects such as an unfused root was offset by the fact that the build-up of weld metal was thicker than the pipe wall, reducing the net stress across the seam, and relatively high strength in the deposited weld metal.

Pipes produced by AOS with single SMAW seams were 30 ft in length. The single SMAW process was replaced by the flash welding process in 1930 because the SMAW process was too slow. The flash welding process as applied by AOS to seams is discussed below.



**Figure 2. Cross Section of Single SMAW Seam**

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<sup>8</sup> KAI archives.

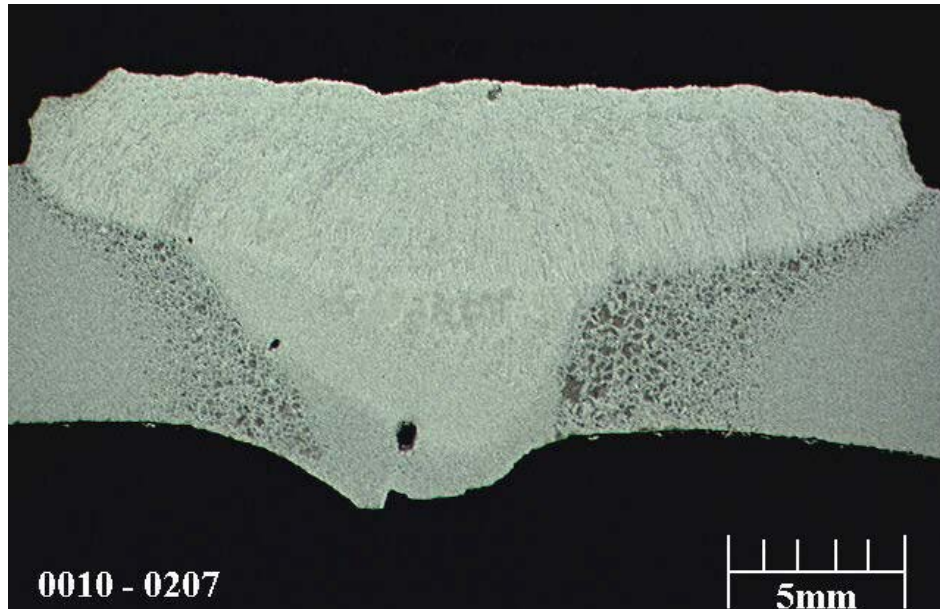


Figure 3. Cross Section of Single SMAW Seam



Figure 4. Typical External Appearance of SMAW Seam



**Figure 5. Typical External Appearance of SMAW Seam**

### Flash Welded Seams

Flash welding is a joining process generally used in industrial manufacturing. Heating is produced by electrical resistance to produce fusion of base materials simultaneously over the entire area of abutting surfaces. The electrical flashing across a gap heats the material to the plastic state. The surfaces are then brought into contact and pressed together to forge a bond.<sup>9</sup> Excess material extrudes lateral to the joint which must then be trimmed. The heating produces a heat affected zone.

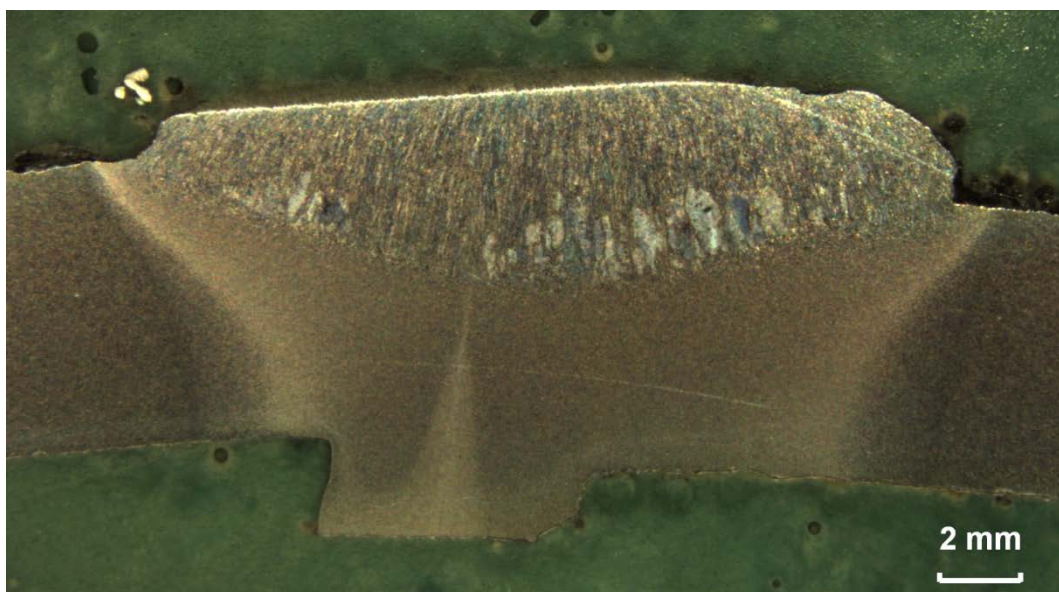
AOS applied the electric flash weld process to pipe production beginning in 1930. Pipes were produced in 40-ft lengths. Plate was formed in presses in a U and then O configuration. The flash weld process used a 1-million-amp current to heat the faying surfaces over the full length of the pipe.<sup>10</sup> The edges were then bumped together to forge the joint and squeeze out oxides. The bumping action caused excess material to extrude radially to form an upset which was then trimmed slightly proud of the pipe interior and exterior surfaces. The upset trim height was nominally 1/16 inch but in practice KAI has observed the height of the upset to vary from zero (flush to the pipe surface) to 1/8 inch.

AOS initially manufactured flash welded seams with a SMAW cover or cap pass. The reasons given for this practice have variously been given as concern for manufacturing

<sup>9</sup> <http://www.thefabricator.com/article/tubepipefabrication/comparing-flash-and-butt-welding>

<sup>10</sup> A.O. Smith Company, Bulletin 576, 1945.

defects in the seam,<sup>11</sup> or concern for susceptibility of the seam to corrosion since cathodic protection was not typically used in that era.<sup>12,13</sup> The period of time this practice was observed has been reported to be 1930 to the early 1940s. An example of this style of seam in cross section is shown in Figure 6.<sup>14</sup> The external appearance would be similar to the all-SMAW seams, while the interior would exhibit a residual square-trimmed upset from the flash weld. Both seam types (all SMAW and FW with SMAW cover pass) were produced during the 1930 transitional year. One way to verify whether pipe exhibiting the wide SMAW cap is 1930 and earlier single SMAW seam or is 1930 and later flash weld seam with SMAW cover pass is to check the joint length, since AOS made pipe in 30-ft lengths in the single SMAW seam era, and 40 ft lengths in the flash-welded seam era. Another way would be to radiograph the seam. The square-cut bead on the interior should have a distinctive appearance in a radiograph.



**Figure 6. Flash Welded Seam with Deposited Weld Cover Pass, ca. 1930**

The flash weld process produced a seam having a characteristic square bead in a width approximately equal to the thickness of the pipe wall, after trimming. Figure 7 and Figure 8 show the typical external appearance of the post-1940 all-flash-welded seam made without a deposited-weld cover pass. Figure 9 and Figure 10 show the typical

<sup>11</sup> Barkow.

<sup>12</sup> Clark.

<sup>13</sup> Lazor.

<sup>14</sup> Photo courtesy of Bill Amend, DNV.

appearance of the flash weld in cross section.<sup>15</sup> The seam in Figure 9 is typical of seams produced during the 1940s while the seam in Figure 10 is typical of seams produced during the 1950s. The untrimmed upset results in a net metal thickness across the seam that is greater than the pipe wall thickness, which reduces the hoop stress acting across the seam.



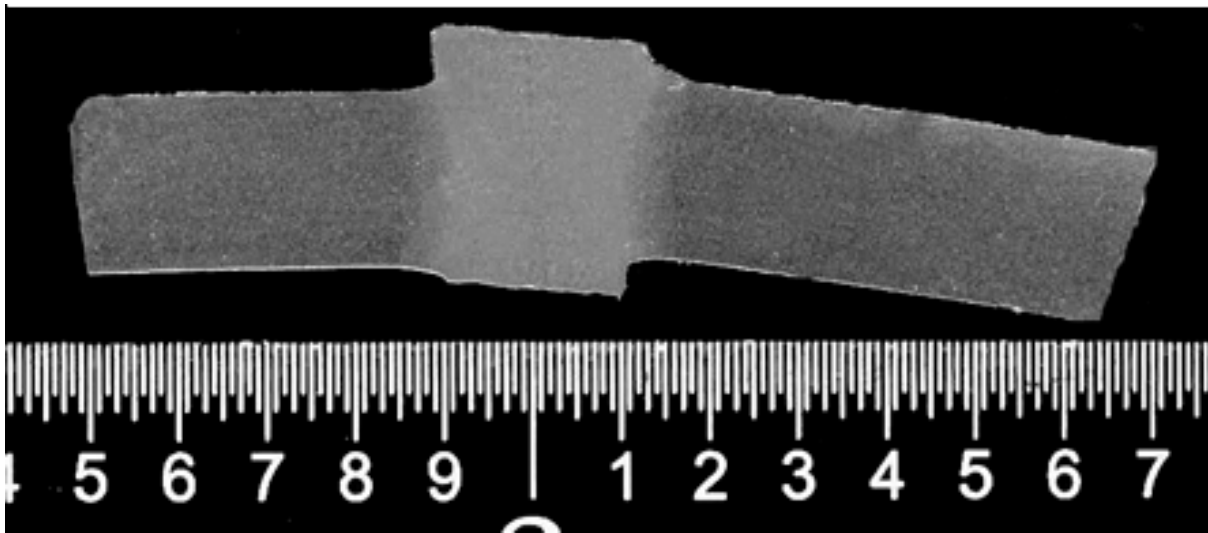
**Figure 7. Typical External Appearance of Flash Weld Seam**

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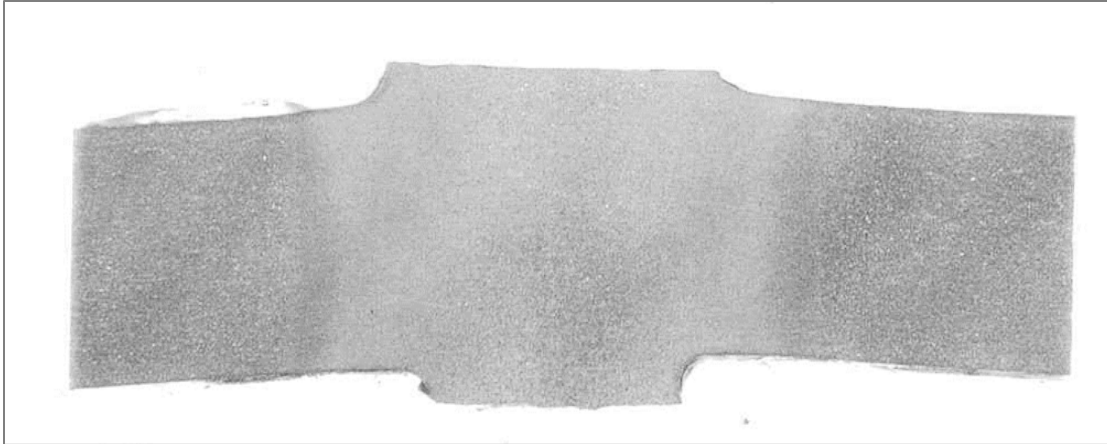
<sup>15</sup> KAI archives.



**Figure 8. Typical External Appearance of Flash Weld Seam**



**Figure 9. Typical Flash Weld Seam Cross Section, ca. 1946**



**Figure 10. Typical Flash Weld Seam Cross Section, ca. 1955**

### **Change to DSAW Seams**

AOS anticipated that future demand would emphasize larger-diameter heavier-walled line pipe and determined that the double-submerged arc welding (DSAW) would be more economical than the flash welding process for manufacturing such pipe. The Houston mill was converted to use the DSAW process in 1969, accordingly.

## **JOINT EFFICIENCY FACTORS**

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### **Origin of the Joint Efficiency Factor**

The Joint Efficiency Factor,  $E$ , represents a generic level of confidence in the overall strength of a weld seam considering the method used to produce the seam, the thoroughness of inspection of the seam's quality, and testing of the seam strength. An on-line literature search and discussion with long-time members of ASME piping standards committees was unable to identify any authoritative documents citing specific data on which historical or present day values for joint efficiency factors are based. It is likely that pipe seam joint efficiency factors were originally developed considering the results of burst tests of pipe performed by major pipe manufacturers. Some manufacturers reported test results in their product catalogs such as those of the National Tube Company of US Steel.<sup>16</sup>

National Tube's catalog presented the results of 366 burst tests of commercially available seamless, lap-welded, and butt-welded pipe (the principal seam technologies

<sup>16</sup> National Tube Company, Book of Standards, 1913.

in the early 20<sup>th</sup> century) in various sizes produced by themselves and other manufacturers, showing average burst stress levels and the number of failures that occurred in the seams. The generic E factors specified for those seam types by the B31 Code many years later appear to reflect the results reported by National Tube in being set at round numbers below the average ratios of burst strengths of samples that failed in the seams to the nominal tensile strength of the material.

The factor “E” was applied in the first (1935) edition of the B31 Code for Pressure Piping in setting the allowed working stress of riveted seams.<sup>17</sup> Effective joint efficiencies were implicit in reduced allowed working stresses for gas piping having various seam types compared with seamless pipe of the same metal strength, for the following seam types: butt-welded (E=0.625), lap-welded (E=0.75), electric-resistance-welded<sup>18</sup> (E=0.85), or electric-fusion-welded<sup>19</sup> (E=0.80) seams. For cross-country gas pipelines and gas pipe outside of urbanized areas, footnotes to the pressure design formula specified the use of a joint efficiency in establishing the working pressure, but the actual joint efficiency values to use were not stated.

The second (1942) edition of the Code<sup>20</sup> specified joint efficiency factors for radiographed fusion-welded (E=0.90), resistance-welded (E=0.85), non-radiographed fusion-welded, forge-welded and lap-welded (E=0.80), and butt-welded (E=0.60) line pipe. API 5L was a listed standard but not API 5LX, which had not yet been developed. A footnote (3) to listings for electric-fusion-welded pipe (30 inches and larger, with reference to ASTM A134) and electric-resistance-welded pipe (API 5L and others) in the “Table 6 Allowable “S” Values for Pipe in Gas and Air Piping System” states:

“Where pipe furnished under this classification is subjected to supplemental tests and/or heat treatments as agreed to by the supplier and the purchaser, and whereby such supplemental tests and/or heat treatments demonstrate the strength characteristics of the weld to be equal to the minimum tensile strength specified for the pipe, the “S” values equal to the corresponding seamless grades may be used.”

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<sup>17</sup>American Standards Association, “Code for Pressure Piping”, American Tentative Standard B31.1, ASME, 1935.

<sup>18</sup> According to nomenclature found in API 5L, electric resistance welded seams and flash welded seams were both classified as “electric welds”. By common usage, flash welded seams were often grouped with ERW seams.

<sup>19</sup> According to nomenclature found in ASTM and API pipe product standards, “electric-fusion-welding” (EFW) referred to welds made by any manual or automatic arc welding process, including single or double submerged-arc welding, or shielded metal-arc welding.

<sup>20</sup> American Standards Association, “Code for Pressure Piping”, ASA Standard B31.1, ASME, 1942.

This same allowance (that E could be taken as 1.00) was reiterated for electric-resistance-welded pipe used in cross-country gas pipelines and non-urban gas pipe in the text discussing determining the effective yield strength to be used for pressure design.

What constituted adequate supplemental test methods and frequency was not stated in the Code. AOS reportedly performed burst tests of produced pipe as a measure of quality control from 1930 into the 1940s.<sup>21</sup> Burst testing conducted by AOS may meet the intent of the stated requirement to perform supplemental tests demonstrating the strength of the pipe. It could also be argued that the process of cold expansion practiced by AOS (discussed subsequently) is a rigorous test of the seam.

### **ASME B31.8**

The first (1952) edition of B31.8 as a separate, integrated standard for natural gas pipelines<sup>22</sup> gives joint efficiency factors for various seam types in Paragraph 807(a): stress relieved and radiographed electric fusion welded (E=1.00), double-submerged-arc-welded in API 5LX (E=0.85), ordinary electric fusion welded (E=0.80), electric-resistance-welded (E=0.85), lap-welded (E=0.80), and butt-welded (E=0.60) line pipe. However, ahead of these specified values for E, Paragraph 807 states:

“The value of E shall be taken from the following list, except that it may be taken as 1.00 for electric-resistance-welded (including electric flash-welded and continuous-electric-resistance-welded) and double-submerged-arc-welded pipe if tests of representative weld-test specimens and/or cylindrical samples demonstrate the strength of the weld to be at least equal to the strength of the pipe and for double-submerged-arc-welded pipe that has been stress-relieved and radiographically inspected...”.

In the 1952 Code edition, the factor E was not used in the pressure design formula, but was used as an adjustment to the effective yield strength which in turn was used to determine the allowed working pressure.

Clearly, the intent of the Code was to allow E=1.00 for pipe having seams reliably and consistently made, by various processes, to have sound quality as demonstrated by

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<sup>21</sup> Clark.

<sup>22</sup> American Standard Code for Pressure Piping, ASA B31.1, Section 8, “Gas Transmission and Distribution Piping Systems”, 1952.

testing. The Code was silent as to the type and quantity of tests required to accomplish that. The phrase “at least equal to the strength of the pipe” is interpreted to mean “at least equal to the *required* strength of the pipe”, not the *actual* strength of the pipe body. When subjected to a sufficiently high stress, the pipe will fail somewhere, either in the body or the seam. If the pressure or stress at failure is greater than the minimum required, it is immaterial what part of the pipe the failure occurs in.

The second (1955) edition of B31.8<sup>23</sup> omitted the inset language above but specifically listed E as equal to 1.00 for DSAW and ERW pipe manufactured in accordance with either API 5L or API 5LX.<sup>24</sup> The factor E was used explicitly in the calculation of the design pressure in an equation that is identical to the present-day calculation in B31.8 and in 49 CFR 192.

ASME B31.8 delisted flash welded seams from the list of pipe Joint Efficiency Factors in the 2010 Edition because such pipe is no longer available new. 49 CFR 192 has listed flash welded pipe with a Joint Efficiency Factor of 1.00 from when it was issued in 1970 through the present time.

## **PROPERTIES OF A.O. SMITH LINE PIPE**

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### **Manufacturing Process**

Prior to 1930 (and for at least part of 1930), AOS produced pipe in 30-ft lengths in Grades B (SMYS of 35 ksi) and C (SMYS of 40 ksi). AOS was not known to have made pipe specified to lower-strength grades of steel (e.g. Grade A with SMYS of 30 ksi, or open hearth Grades I or II with SMYS of 25 ksi and 28 ksi, respectively), nor wrought iron. AOS introduced belled-end pipe to facilitate arc welding in the field, which was an evolving practice in the late 1920s.

Starting in 1930, in conjunction with the switch to the flash-welded seam process, AOS introduced hydraulic cold-expansion of the pipe (after seam welding). AOS stated in its

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<sup>23</sup> “Gas Transmission and Distribution Piping Systems”, Section 8 of the American Standard Code for Pressure Piping, ASA B31.1.8, 1955.

<sup>24</sup> Supplemental tests consisting of destructive tests performed on a sampling basis called for in API 5L and 5LX at that time may have been deemed adequate at that time. API 5L and 5LX did not make nondestructive examination of seams a requirement until the 20<sup>th</sup> and 11<sup>th</sup> Editions, respectively, issued in 1963, however some manufacturers were performing on-line examination in the 1950s.

promotional literature that it used “stronger steel” in their pipe.<sup>25,26</sup> The cold expansion served both to control final dimensions and increase the strength of the pipe, and was a stringent test of the strength of the seam. The amount of expansion was typically 1 to 1.7% of the diameter.<sup>27</sup> AOS claimed that the cold work from the expansion process increased the strength of the pipe by around 10 ksi relative to the initial plate properties. The hydraulic expander was used in Milwaukee from 1930 until 1949. It was replaced by a mechanical expander developed by AOS, in 1950 in Milwaukee and in 1951 in Houston.

AOS also practiced hydrostatic pressure testing to a high percentage of the specified minimum yield strength (SMYS) early on. The author reviewed pipe purchase specifications from 1931 which required testing to 80% of SMYS, and specifications from 1933 and 1937 requiring testing to 90% of SMYS, so testing to this level was practiced early in the post-1930 flash weld seam era, though perhaps only as requested by the purchaser.<sup>28</sup> Testing to 90% of SMYS became a standard AOS practice in 1940.<sup>29</sup> For many years, AOS was testing to higher pressure levels than the minimum test levels specified in API 5L or 5LX. Prior to 1942, API 5L only required mill pressure tests to 40% to 50% of SMYS. Starting in 1942, pressure testing of Grades A and B was increased to 60% SMYS; high strength grades of pipe were only required to be pressure tested to 85% SMYS in 1949, and large diameter pipe was not required to be pressure tested to 90% SMYS until 1956.<sup>30</sup> Thus AOS mill testing practices significantly exceeded general industry requirements until 1956. As already mentioned, AOS also performed burst tests of pipe as a measure of quality control, a practice that was never required in API 5L.

AOS production of pipe using the flash-welding process preceded recognition of the process by pipe product specifications by several years, though it is noted that this was

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<sup>25</sup> Graham.

<sup>26</sup> A.O. Smith Company.

<sup>27</sup> Kiefner and Clark.

<sup>28</sup> The author also reviewed a 1930 pipe purchase specification for AOS Grade B pipe in 16-inch, 20-inch and 22-inch sizes, calling for a mill test to a minimum hoop stress of 20 ksi. This corresponds to only 57% of SMYS in accordance with the minimum requirement of API 5L. The joint lengths were specified to be 30 ft, indicating the pipe produced for this order would have been made with deposited groove weld process, not the flash weld process. This indicates that early AOS pipe was not necessarily made to superior standards relative to API 5L. However, AOS's ability to produce higher-strength, higher-tested pipe was a key selling point with the flash-welded seam pipe.

<sup>29</sup> Barkow.

<sup>30</sup> Kiefner, J.F., “Evaluating the Stability of Manufacturing and Construction Defects in Natural Gas Pipelines”, Report to DOT and INGAA, Contract No. DTFAAC05P02120, April 26, 2007.

the case for electric-resistance welded (ERW) seams as well.<sup>31</sup> The electric flash weld was specifically listed as an approved seam production method in the API 5L 9<sup>th</sup> Edition, 1954, and the 5LX 1<sup>st</sup> Edition, 1948. API 5L and 5LX maintained recognition of the flash-welding process until 1982. AOS received an API monogram for the Milwaukee plant in 1955 and for the Houston plant in 1957.<sup>32</sup> The delay in AOS acquiring API certification should not be interpreted as indicating that the attributes of pipe produced prior to those dates was inferior to pipe manufactured to the requirements of API 5L or 5LX pipe. On the contrary, the author believes the delay in acquiring API certification reflected the fact that prior to then, AOS often worked to custom purchase specifications (a common practice) to manufacture pipe that was typically superior to the minimum specified requirements of API 5L and 5LX in terms of material strength and pressure test level. In that circumstance, an API monogram was perhaps not viewed as necessary.

It is likely that the combination of cold expansion and high-level pressure testing enabled AOS pipe to experience fewer seam-related problems than ERW pipe of similar vintages.<sup>33</sup> These manufacturing steps do not cause better seams to be manufactured because the seams were already formed ahead of those steps. Flaws such as hook cracks have been discovered in AOS flash welded seams. However, grossly defective seams could not have withstood either or both manufacturing steps while remaining intact, so only seams with comparatively minor flaws could have been present in finished pipe that was shipped to customers.

In response to claims by manufacturers of DSAW seam pipe touting their radiographic inspections, AOS installed ultrasonic seam inspection in both plants in 1957. Weld seam normalizing was introduced in both plants in 1966-1967.<sup>34</sup>

## AOS Pipe Integrity Concerns

Flash welded seams are a form of forged autogenous weld similar to ERW seams and are potentially susceptible to similar manufacturing defects such as bond-line lack of fusion and hook cracks. However, owing to the cold expansion process and the very

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<sup>31</sup>The first definition in API 5L of the term “electric welded pipe” as pipe having seams joined by electric welding without addition of extraneous metal” appeared in the November 1942 Supplement to the May 1942 8<sup>th</sup> Edition. That definition mentioned both ERW and flash-welding processes.

<sup>32</sup> Kiefner and Clark.

<sup>33</sup> Kiefner and Clark.

<sup>34</sup> Kiefner and Clark.

high mill test relative to what was practiced with ERW seams, such defects are likely to be much smaller and more benign than conditions exhibited in some ERW seams.<sup>35</sup> Thus any susceptibility should not be construed as significant limitations on the flash weld Joint Efficiency Factor. A San Bruno-like incident where a failure occurs in a seam defect that barely survives a hydrostatic test to 1.25 times the MAOP is unlikely because the cold expansion and high mill test employed by AOS would have already eliminated pipe with such gross defects.

Some batches of AOS pipe produced between 1952 and 1957 were affected by large (i.e., dinner-plate size) hard spots in the pipe body, owing to uncontrolled thermal events in the plate rolling mill.<sup>36</sup> These conditions do not affect the seam or the Joint Efficiency Factor.

AOS pipe can experience grooving or selective corrosion of the seam bond line, similar to what can occur with ERW seams. While such a condition may pose a serious integrity threat, it is not a reflection of original seam manufacturing quality and should have no bearing on the Joint Efficiency Factor. If that particular integrity threat exists, it is mitigated through appropriate integrity management practices, not by adjusting the Joint Efficiency Factor which is solely for design purposes.

## **KAI Database**

KAI maintains a database of pipe materials test results, which contains the results of testing of 42 samples of AOS pipe. In addition, results from 5 additional sets of tests were reported to KAI. All were confirmed to have flash-welded seams except 5 all-single SMAW seams and one DSAW seam.

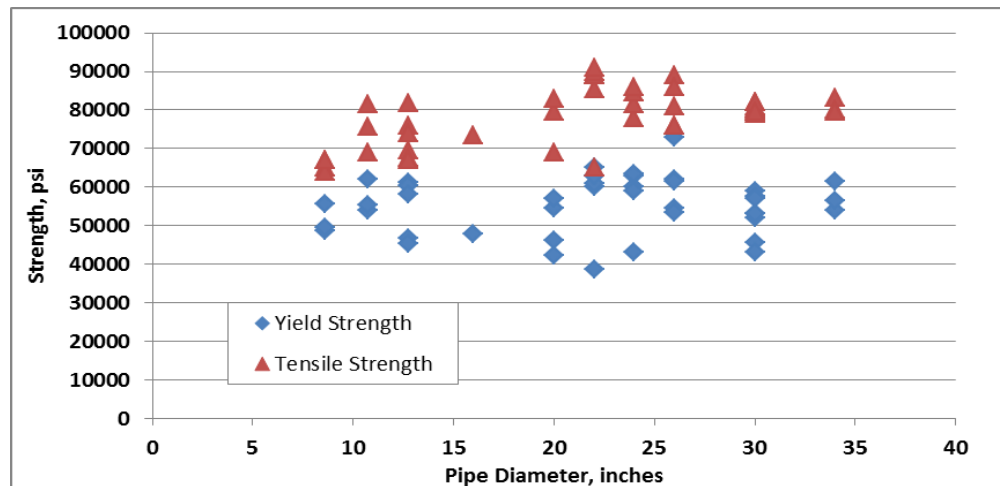
The product years of tested pipe samples ranged from 1929 to 1967; sizes ranged from 8.625-inch OD to 34-inch OD. Approximately 2/3 of the pipe samples in our database that were manufactured prior to 1950 were 20-inch diameter and larger.

Figure 11 shows variation in pipe body strength properties with pipe size. There is no evident trend of pipe strength varying systematically with pipe size.

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<sup>35</sup> Kiefner and Clark.

<sup>36</sup> Clark, E.B., Leis, B.N., and Eiber, R.J., "Integrity Characteristics of Vintage Pipelines", INGAA Foundation, 2005.



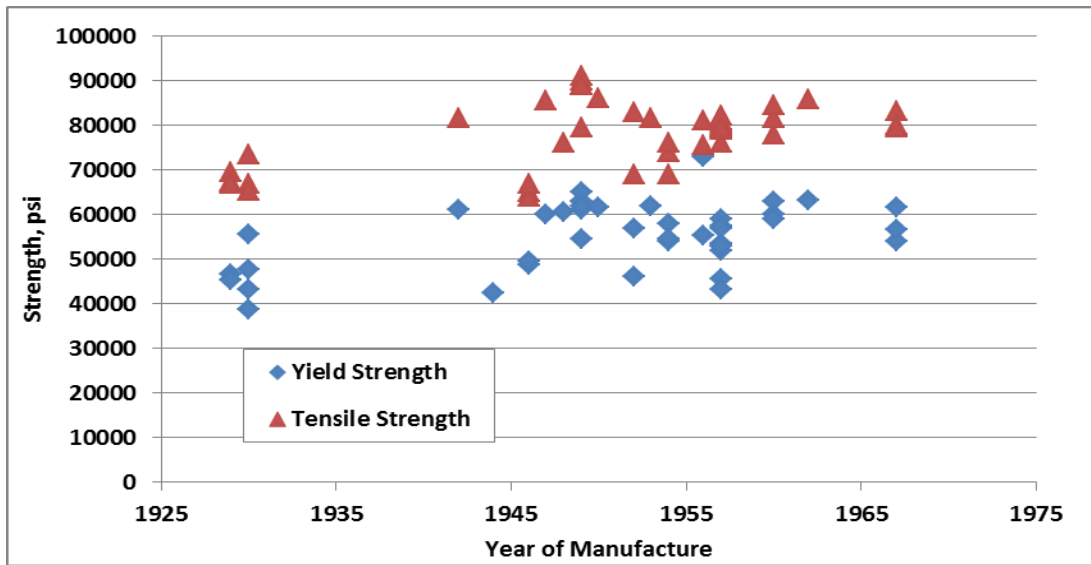
**Figure 11. Variation in Pipe Body Strength with Pipe Size**

Figure 12 shows the variation in tested mechanical strength properties of the sample materials by year of manufacture. The tests were performed in the pipe body in accordance with methods specified in API 5L or 5LX for the reported year of manufacture. While these are not tests of the seam, in all post-1930 pipe the seam underwent the cold expansion process, exhibiting sufficient strength to withstand plastic deformation of the pipe body. There is only a slight trend of increased strength with newer pipe samples. AOS pipe manufactured in 1930 is likely to have about the same strength as AOS pipe manufactured in later decades.

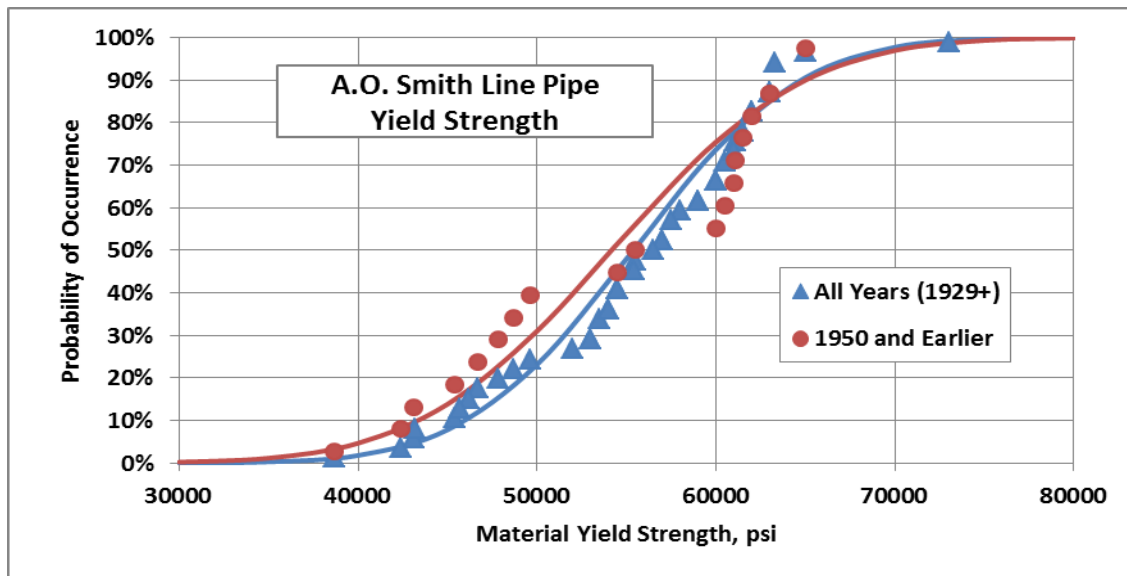
Figure 13 shows the cumulative probability of occurrence of actual material yield strengths for pipe in KAI's database that was manufactured by AOS in all years (blue symbols), and pipe manufactured by AOS prior to and including 1950 (red symbols). Both groupings show a similar distribution, although there was more scatter in the older vintage group. Nevertheless, older vintage AOS pipe is not significantly more likely to have low strength than newer AOS pipe. Figure 13 suggests that the data represents three distinct strength populations (low, medium, and high), each with their own unique cumulative distributions. However, from the standpoint of a user attempting to determine a probable minimum strength, the entire population could be considered.

If the samples tested are representative of the population of pipe produced by AOS, the data suggests that there is a negligible probability of AOS pipe having actual yield strength below 35 ksi, corresponding to the specified minimum yield strength of API 5L Grade B pipe. The material grades of the pre-1950 pipe samples were reported to us

as Grades B, X45, X52, and “Unknown” (the 1929 and 1930 samples, having actual yield strengths of 45 to 55 ksi). No samples of AOS pipe received by Kiefner for testing were ever reported as a designated grade below Grade B. This is consistent with AOS only making Grade B or Grade C pipe in early years as discussed previously. Based on this information, it is highly unlikely for any pipe identifiable as AOS pipe of any type to be a lower strength grade than Grade B.



**Figure 12. Variation in Mechanical Properties by Year Made**



**Figure 13. Probability of Occurrence of Minimum Strength**

## Sample Testing

An operator may wish to perform materials testing of sample early vintage AOS pipe from their system. Tests should include transverse tensile tests in the pipe body and across the flash welded seam. It was not uncommon prior to 1960 for pipe to be manufactured in accordance with a custom pipe product specification agreed between the purchaser and manufacturer. AOS engaged in this practice routinely since they were capable of making pipe stronger than the grades recognized in API 5L.

Tensile properties could be slightly higher in the base metal than the seam. This should not be interpreted to mean that the joint efficiency factor should be derated proportionately, for the following reasons. First, seams and welds are required by all pipe manufacturing specifications and welding specifications to exceed the minimum tensile properties specified for the base metal, but no specification requires that the seam or weld properties exceed the actual base metal properties where those are in excess of the specified minimum value. Second, the actual seam is thicker than the wall in the pipe body, so the net seam is often stronger than the pipe body. If the pipe were pressure tested it would be expected to fail in the pipe body, not the seam. As a final point, it should be noted that any tensile test performed on a pipe represents a small sample that does not reflect the full variation in actual properties.

## SUMMARY OF FINDINGS

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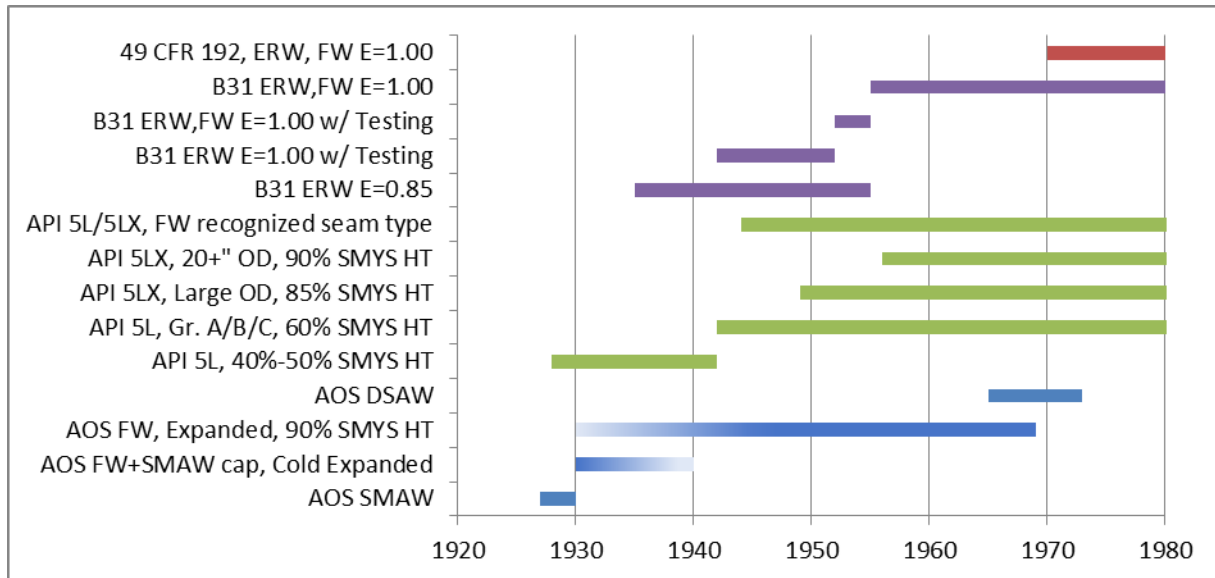
Most pipe manufactured by AOS is viewed through some lenses today as having been manufactured by what is now outmoded technology. Consequently AOS pipe is sometimes also viewed as inferior. However, AOS introduced important innovations in pipe making including cold expansion for dimensional control and strength, hydrostatic pressure testing to a high level, and high yield-strength pipe. The practices introduced by AOS enabled their pipe to be as good as or better than other varieties of pipe available during the applicable eras of production.

A timeline of key phases of AOS production, along with applicable requirements in ASME codes and Federal regulations is presented in Figure 14.<sup>37</sup> The early era of flash welded seams with SMAW overlay is shown with an indistinct upper bound time frame of around 1940, while the subsequent era of flash-weld-only production is shown with

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<sup>37</sup> In the figure, "HT" is an abbreviation for "hydrostatic test". Also the terms "cold expanded" and "expanded" are equivalent.

an indistinct lower bound time frame prior to 1940, due to a lack of definitive information available at the time this report was prepared.



**Figure 14. Timeline of AOS Production Phases and Standards Requirements**

Results from pipe properties tests confirm that any pipe identified as an AOS product is unlikely to be of lower strength than Grade B, even if the actual grade the pipe was manufactured to is no longer known from records. AOS flash-welded seam pipe is susceptible to specific forms of degradation in service. However, these concerns are addressed through integrity management practices, not a joint efficiency factor for design purposes.