

Why Spiral Weld Pipe?

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What are the main reasons behind the boom in the use of spiral-weld pipe? Among reasons cited here by the author are better weldability, fewer field welds, smaller tolerances, higher strength steels, and inherent safety margins

In attempting to explain why spiral-weld pipe is beneficial for the user and what are the characteristics which make it a safe product, this article deals with the past and the present and also takes a look at the future.

Spiral-weld pipe was first introduced on an industrial basis in the 1880s in the United States.⁽¹⁾ The aim was the same as for gun fabrication in the Middle Ages: to beat the ratio of π between the widths of pipe diameter and the base material.

The solution to this problem offers numerous advantages:

(1) Holding a limited number of widths in raw material stocks suitable for various pipe diameters merely by changing the angle of the weld in the joint;

(2) The possibility of producing large-diameter pipe by means of a relatively uncomplicated process—compared with two, three or more seams in longitudinally-welded pipe;

(3) The possibility of correctly producing thin-walled pipe;

(4) Achievement of a lower investment for a pipe mill of a given capacity.

All these advantages are still valid.

Why was spiral-weld pipe only accepted as a high-pressure pipeline material in the last decade? The answer is simple: simultaneous control of forming and welding in the spiral-weld pipe machine could not satisfactorily be applied earlier. Various welding processes (forge welding, electric resistance welding, external submerged-arc welding, high-frequency welding) had been applied, but were not as successful as internal and external submerged-arc welding. Only spiral-weld pipe produced by this method has been approved as a top-quality product. This is very much the same as in the field of large diameter, longitudinally-welded pipe.

Improvements in machinery construction, rolling practice

for the raw material, application of a suitable welding process and subsequent non-destructive testing technique have been necessary to bring spiral-weld pipe production up to the present state of the art.

Present mills for spiral-weld pipe consist of a de-coiling device (in the case of wide-strip base material) or a plate preparation table (where the base material is in plate form), a strip-connecting welder, straightening rollers, edge-preparation tools (shearing and trimming), pre-bending devices, a three-roller bending and cage-forming system, an internal welder, an external welder (both submerged-arc), ultrasonic testing apparatus, and cutting devices.

The material passes through all these production stages continuously. The angle between the flat strip being fed into the machine and the finished pipe leaving the machine controls the pipe diameter in ratio to strip width and the angle of the weld in the pipe. Relationships between the various influence factors are shown in Fig. 1 for the operation area in which spiral-weld pipe is produced, in comparison with straight-seam pipe using one or two longitudinal welds. The range from 10-inch up to 80-inch diameter is indicated in this self-explanatory diagram and is related to the range of widths in which coils or plates are available. (2)

In the future, larger-diameter pipe will be needed with heavier wall thicknesses for increasing operating stresses. By the use of improved rolling methods and heavier coilers in the strip mills, spiral-weld pipe will follow this development with thicker strip as the base material; in extreme cases plates can easily be used.

A new method of splitting up the spiral-weld pipe process into a forming and tack-welding operation and an independent simultaneous internal and external welding operation will improve the process economically. Even in the case of Q+T grades, the axial symmetry of the product may be an advantage.

There is a two-part answer to the question: why is spiral-weld pipe beneficial for the user? These two parts have to do with tolerances and TM-steels (Thermo Mechanical).

Tolerances

The use of narrower raw material, compared with one-seam longitudinally welded pipe, means closer wall-thickness tolerances. Furthermore, the process itself does not rely on individual dies for every diameter. Pipe can be produced based on the I.D., O.D., or on any agreed diameter - which also allows a wide variety in choosing the most economical diameter for a certain project. The diameter tolerance is small, particularly with regard to ovality; and the pipe, due to its axial symmetry has an inherent straightness. No calibration process (expanding or roll sizing) is necessary. End and body tolerances of a joint are more or less the same.

Such tolerances relate directly to the design of submarine pipelines, in which out-of-roundness of the pipe becomes a controlling factor in determination of the wall thickness. It is clearly apparent that an increasing ovality of a pipe reduces its capacity to bear external pressure. With Timoshenko's analysis of a ring with an initial ellipticity, a reduction of the standard ovality can be related to an increase of the safety factor; or, on the other hand, to a possible reduction in wall thickness with exactly the same safety factor quantitatively.

Fig. 2 shows a computer print-out of the following formula which is developed from Timoshenko's analysis:

$$d = \frac{r}{\gamma} \left\{ S + \frac{r^2 E}{1-\mu^2} \left(\frac{3e}{100r} + 1 \right) - \left[S^2 + \frac{r^2 E}{1-\mu^2} \left[\frac{r^2 E}{1-\mu^2} \left(\frac{3e}{100r} + 1 \right)^2 + 2S \left(\frac{3e}{100r} - 1 \right) \right] \right\}^{0.5}$$

where d = collapse depth (inches); r = ratio WT/OD; S = stress level in the pipe wall (psi), γ = specific density of the water above the pipe (lb/cu in); E = modulus of elasticity of the steel (psi); μ = Poisson's ratio; and e = ovality of the pipe, in percent.

For determining S , a sufficient factor of safety to SMYS should be used and the distortion energy hypothesis may be taken into account. For the special case $e = 0$ (theoretically round pipe), the formula is identical with the well known equations

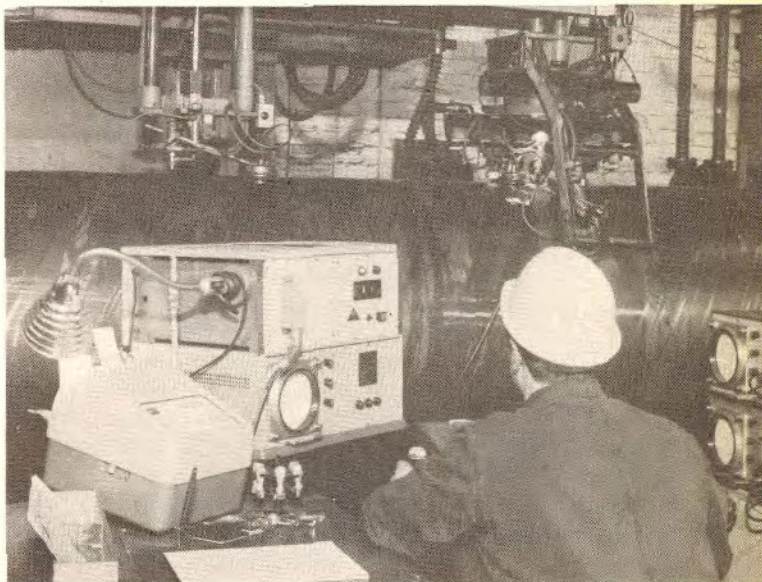
$$d \cdot \gamma = P \frac{2r^3 E}{1-\mu^2} \quad \text{or} \quad r = \sqrt[3]{\frac{P(1-\mu^2)}{2E}}$$

where P is a uniform external pressure.

The data in Fig. 2 show a substantial increase of safety against collapse on mean stress levels, by a reduction of the specified ovality to half the standard value. Consequently, a smaller wall thickness can be used by choosing the same safety factor. Detailed computer analyses are available.

No wonder that the world's largest offshore submarine pipelines in Kuwait and Nigeria were constructed of spiral-weld pipe.

Even the choice of pipe-joint cut-off length offers economic



Automatic ultrasonic testing machine.

MEET THE AUTHOR



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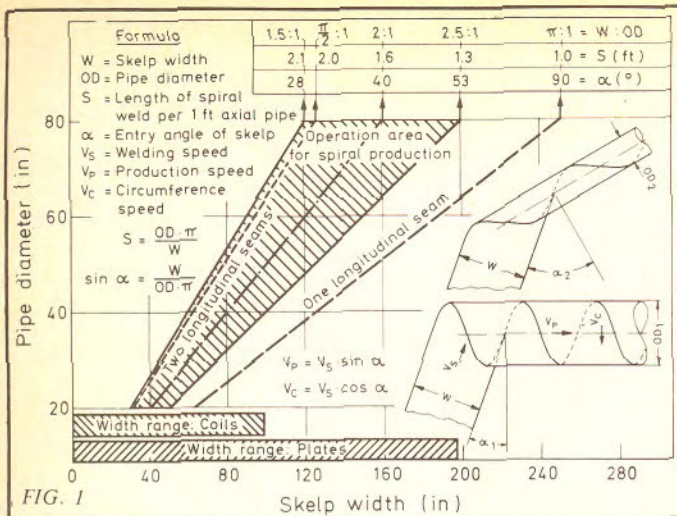


FIG. 1 — Criteria of welded pipe production.

FIG. 2 — Collapse depth of submarine pipes: collapse depth in feet of sea water ($\gamma = 0.03721 \text{ lb/cu inch}$). Note that the depth is reversely proportional to γ and that the figures are given with floating point.

FIG. 3 — Chemical composition of TM-steels.

FIG. 4 — Results of IIW tests.

FIG. 5 — Stress distribution

FIG. 6 — Results of international pressure cycle test of DSA spiralweld pipe recently produced.

$R = 0.010$

OVALITY (%)	STRESSLEVEL PSI									
	10000	20000	30000	40000	50000	60000	70000	80000	90000	100000
	DEPTH FT.									
0.10	0.130E 03	0.140E 03	0.143E 03	0.144E 03	0.145E 03	0.146E 03	0.146E 03	0.146E 03	0.147E 03	0.147E 03
0.50	0.915E 02	0.116E 03	0.126E 03	0.131E 03	0.134E 03	0.137E 03	0.138E 03	0.139E 03	0.140E 03	0.141E 03
1.00	0.685E 02	0.955E 02	0.109E 03	0.117E 03	0.123E 03	0.126E 03	0.129E 03	0.131E 03	0.133E 03	0.135E 03
1.50	0.551E 02	0.817E 02	0.968E 02	0.106E 03	0.113E 03	0.118E 03	0.122E 03	0.124E 03	0.127E 03	0.129E 03
2.00	0.463E 02	0.715E 02	0.870E 02	0.974E 02	0.105E 03	0.110E 03	0.115E 03	0.118E 03	0.121E 03	0.123E 03

FIG. 2

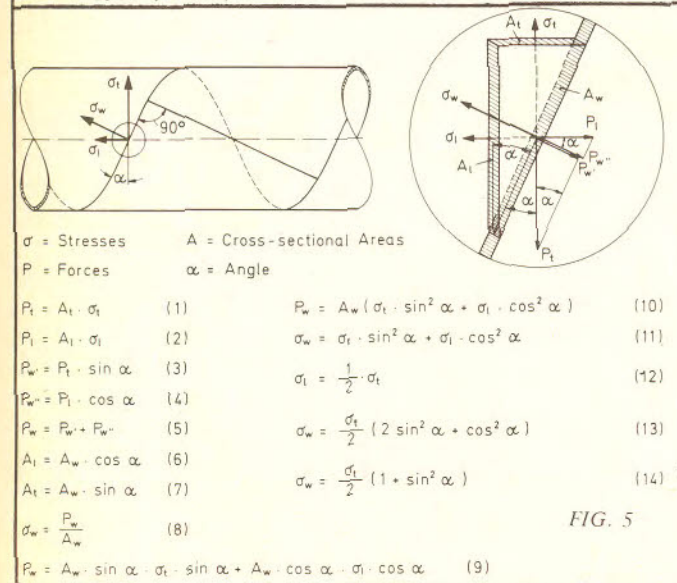


FIG. 5

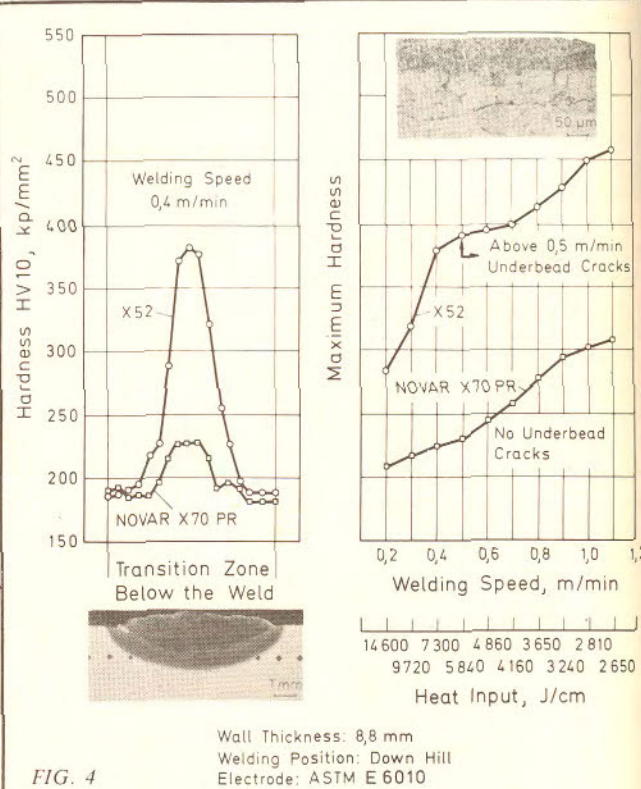


FIG. 4

Designation	Chemical Composition (%) (4)								Equivalent API GRADE	
	C max.	Si max.	Mn max.	P max.	S max.	V max.	Cb max.	Al		
NOVAR X 52 PR	0.12	0.25	1.40	0.030	0.025	0.08 ¹⁾	0.05 ¹⁾	*)	*)	X 52
NOVAR X 56 PR	0.12	0.30	1.45	0.030	0.025	0.08 ²⁾	0.05 ²⁾	*)	*)	X 56
NOVAR X 60 PR	0.12	0.30	1.45	0.030	0.025	0.08 ²⁾	0.05 ²⁾	*)	*)	X 60
NOVAR X 65 PR	0.12	0.35	1.50	0.030	0.025	0.08 ³⁾	0.05 ³⁾	*)	*)	X 65
NOVAR X 70 PR	0.12	0.35	1.50	0.030	0.025	0.08 ³⁾	0.05 ³⁾	*)	*)	X 70
NOVAR X 75 PF(5)	0.016	0.33	1.35	0.021	0.018	0.06	0.04	0.02		X 75

1) V + Cb max. 0.08%
 2) V + Cb max. 0.10%
 3) V + Cb max. 0.12%
 4) as necessary for fine grain structure
 5) Cu + Cr + Ni + Mo max. 0.50%

FIG. 3

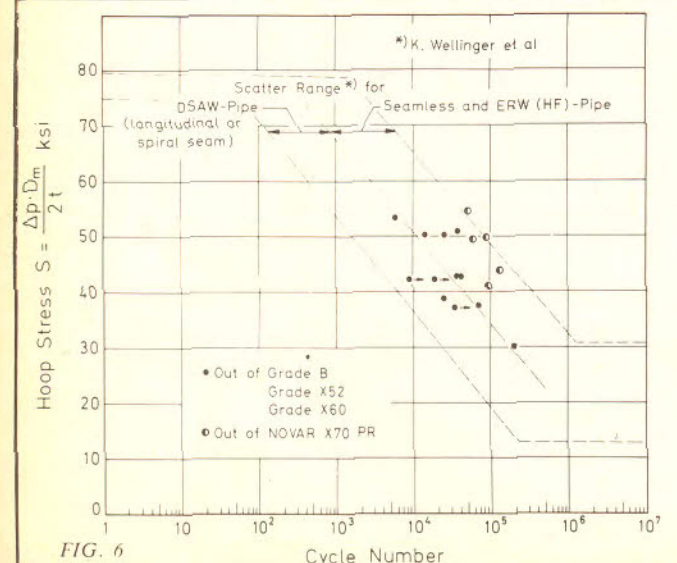


FIG. 6

advantages. On the one hand, a longer standard length reduces welding cost compared with 40-ft standard joints—in cases where the right-of-way allows long joints or multiples to be used.

On the other hand, when shorter joints are required for transport and/or construction reasons, individually tailored lengths can be shipped to difficult sites. This can be important for mountain areas. Since the product leaves the spiral-weld pipe machine in a continuous, infinite length, such customers' orders easily can be fulfilled without loss of material. In fact, only for the hydrotest in the mill and for transportation reasons do joints have to be sliced off the endless pipe. Thus, high average lengths and small-length tolerances automatically are typical properties of spiral-weld pipe.

Better weldability or weldability under extreme conditions (e.g., the Arctic) are required more and more. The answer is TM steel (Thermo-Mechanical treated steel). This type of material can show an outstanding low carbon equivalent and permits increase of the SMYS figures to higher values, such as 70 ksi or 75 ksi, with an even safer pipe and without the use of Q + T technique.

The chemical composition of TM-steels can be seen in Fig. 3. Most of the TM-steels are marketed under registered trade marks such as NOVAR (Never Overlook Valuable Advantages Revealed), PR stands for Perlite Reduced and PF for Perlite Free. The properties of these steels are reached by the development of precipitations of vanadium and/or columbium carbonitrides in such a distribution and size that dislocations are held back from moving through the lattice. A simultaneous reduction of the grain size results both in an increased strength level and a decreased transition temperature.

All this means an increase of the yield point fairly independent of the carbon content and requires a specially controlled rolling practice. The rolling program for such steels includes chemical analysis, slab temperature, rolling temperature, thickness reduction in the various rolling stands, cooling rate and coiling temperature. The details can be taken from references. ^(6 & 7)

The NOVAR steels show excellent welding behavior (see Fig. 4), excellent ductility, and during K_{IC} -determination very low transition temperatures to 100 per cent brittle fracture. In addition to the special controlled rolling practice, reduced sulfur contents or REM can be used in influencing impact properties. Of course, TM-steels can be rolled in plate mills, too, but at present their most beneficial results are achieved on wide strip mills and for large-O.D. pipe are therefore related predominantly to spiral-weld pipe.

Safety Characteristics

First of the characteristics of spiral-weld pipe which make it a safe product is the perfect I.D./O.D. welding control. By means of mechanical guiding systems or pilot line control systems, a minimum of misalignment is achieved. A main advantage of spiral-weld pipe technology is the possibility of non-destructive testing of the weld immediately after the simultaneous inside and outside welding operation, so that there is no chance of a major production of questionable welds. ⁽⁸⁾ The I.D.-welder (on the bottom), the O.D.-welder (on the top) and the ultrasonic testing device following one winding behind the O. D.-welder on the top are in one line. Welding and testing has become an integrated operation.

Besides the standard mechanical tests for line pipe such as YS, TS, CV, DWTT, visual inspection and tolerance control, all spiral-weld pipes are tested again by non-destructive methods after the hydrostatic test and before leaving the mill. New methods of ultrasonic testing have been developed which allow the detection of longitudinal and transverse

flaws simultaneously, with an effectiveness control of the equipment and an automatic sensitivity control of the complete system.

Moreover, not only can the weld be inspected by using this machine, but also the the base material is checked as well as the ends of the joint in order to prevent field welding troubles due to laminations. By this control system, every inch of the spiral weld is double-checked; in addition it is only loaded with about 50-70 per cent of the hoop stress (see Fig. 5) under working pressure.

Equations (12) to (14) in Fig. 5 are valid for pipes closed with caps. When recalling that $\alpha = \text{arc sine } W/D\pi$ where W = width of strip used for spiral-weld pipe production; D = pipe diameter; and α = angle (see Fig. 5), and using the standard W/D ratio in spiral-weld pipe production, the limitations of stress in a spiral weld are found.

Taking statistics into consideration, this means that only in those cases where the axial stress and the hoop stress in the joint are equal (which is very seldom), the stresses applied to the weld in a spiral-weld pipe are of the same level as in the weld of a longitudinally-welded pipe. In some cases, the stress in the weld of a spiral-weld pipe is less than the stress in the seam of a longitudinally welded pipe. Since both welds have the same weld efficiency factor of 1.0, this means that the weld of the spiral-weld pipe is "over designed," or in other words has an inherent safety margin. This can be seen, for instance, from the results of cycle test ⁽¹⁰⁾ (see Fig. 6).

Also in burst tests, both hydrostatic and by air pressure, a typical crack runs only a short distance parallel to the axis in accordance with the main stress direction and then turns into a circumferential direction parallel to the rolling direction which is simultaneously paralleling the weld. Both the shear stresses and the longitudinal/transverse properties of the base material in relation to the main stress direction develop this beneficial crack-arresting phenomena, which is supported by the very high notch ductility level in spiral-weld pipes transverse to the pipe axis.

Ever increasing demands for spiral-weld pipes will increase production capacity. Modern spiral-weld mills are at present assembled or planned in various parts of the world. Also, the ANSI Codes B 31.4 and B 31.8, as well as the API specifications, have recognized the present state of the art of spiral-weld pipe production. So, not only for a few specialists but for all pipeliners, spiral-weld pipe has become a standard product having specific advantages.

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ARTICLES OF INTEREST THIS MONTH

South European Pipeline Tripling Capacity by 1980	14
Trans Alaska Line Pipe is given Protective Coating	13
Final Routing for Ekofisk Oil Line Still Not Certain	14
Special Techniques Used in Dutch Pipeline Projects, by Brian C. Hague	18
Why Spiral-Weld Pipe? by Wolfgang Schmidt	28
Trends in Oil Pipeline Building in the U.S.S.R., by Anatoli Tishchenko	24
The World's Pipelines—1972	33

DEPARTMENTS

International News and Notes	7
Message from the Editor	17
What's New in Equipment and Services	44
Oil Industry Staff Changes	45
News of Suppliers	47
Production Statistics	48
Advertisers Index	48

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