Applications of centrifugally-cast alloy piping and pipe fittings in onshore and offshore oil and gas production

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INTRODUCTION

The petrochemical and oil refining divisions of major oil companies have for many years been extensive users of centrifugally-cast alloy pipe and tube mainly, though by no means exclusively, for high-temperature furnace tubes in steam hydrocarbon reforming furnaces for production of hydrogen, ammonia, methanol synthesis gas and in stream cracking furnaces for olefin production.

On the contrary, the oil and gas production sectors have until the last few years made very little use of centricast pipe and tube; notable exceptions are the fairly extensive use of centricast bodies in austenitic and duplex stainless steels for barrel pumps for water injection service and centricast aluminum bronze spools for rising mains for seawater pumps on offshore platforms. However, in recent years there have been cases where centricast heavy wall alloy tubes and pipes have been used with considerable economic benefit and in some cases have substantially eased heavy wall pipe availability/delivery problems, particularly where relatively small quantities of pipe are involved. Such applications have, to date, included onshore flowlines, stainless subsea manifolds in duplex stainless steel, Christmas tree flow loops in martensitic stainless steel and topside production and test manifolds, in medium nickel alloys.

An important development emanating from pipe foundries is the production of internally-clad steel pipe using centrifugal casting techniques. Production of bimetallic pipe by centricasting is itself not a new technique, formerly having been applied to high-temperature petrochemical furnace tubes to obtain the best combination of external corrosion resistance and pressure-containing capability at high temperature. In the last few years, however, centricast piping with corrosion-resistant alloy internal cladding has been commercially developed and, equally important, clad fittings are now available. Cast carbon steel (API X52, X60, X65) pipe with internal cladding of C276, 316L, Alloy 825 and Alloy 625 have been used for flowlines either for geothermal plant or oilfield application.

1. PRODUCTION OF CENTRIFUGALLY-CAST PIPE AND FITTINGS

Centrifugal casting to produce pipes, tubes and tubular components is a long-established method of making high-integrity castings and has been extensivley applied to cast irons, carbon and low-alloy steels, copper-base alloys, ferritic, martensitic, duplex and austentic stainless steels, high performance corrosion-resisting and heat-resisting steels, medium and high-nickel alloys, cobalt-base alloys, etc.

There are two basic forms of centrifugal casting:

(a) Horizontal axis spinning

(b) Vertical axis spinning

Both involve casting molten metal into rapidly rotating moulds or dies. Which process is used depends on the L/D ratio and in some cases the wall thickness and specific application. As a broad generalization the vertical centrispinning process would be chosen where L/D<2. *(Reference 1)*

Metal moulds are nowadays used exclusively for production of long tubes or pipes up to e.g. 4-6m length by horizontal spinning. *Figure 1* shows a batch of heavy wall CF3M pipes delivered for a North Sea project.

Vertical spinning may involve metal dies, graphite dies, sand or ceramic moulds inserted in the metal die to enable the formation of profiles on the outer surface. *Figure 2* shows several examples of vertically-spun castings in duplex and austentic steels for oil industry applications. Balls for ball valves are now regularly produced as vertically-spun castings *(Figure 3a)* and vertical centrispinning (e.g. rings and flanges) up to about 3m diameter are not uncommon. Some foundries have adopted vertical spinning techniques to the production or tee fittings *(Figure 3b)* and even for manifold sections incorporating four or more integrally cast outlets. (See *Figure 3c.)*

Two main characteristics of centrifugal castings, namely the essentially directional solidification in metal moulds and the high centrifugal force, combine to ensure a high degree of soundness. Nonmetalic inclusions are forced towards the bore and any microshrinkage is confined to the immediate bore zone which is removed by machining. An exceptionally high degree of soundness and cleanliness through the pipe wall is acheived; experience shows that if die penetrant test on outer and bore surface are satisfactory then the probability of any internal defects is extremely low. There is no significant difference between longitudinal and transverse properties and even through-thickness properties in centricast pipe.

Because centricast pipe and tube are normally bore-machined as an integral part of production, cast pipe can be supplied to much tighter tolerances on wall thickness, ID and roundness than wrought seamless or longitudally welded pipe. Advantage can be taken of these tighter tolerances in piping designs with some potential weight and cost saving. Similarily in fabrication, advantage can be taken of the tighter tolerances, for example, in fabricating items such as manifolds, which if they are to be pigged, may have to be fabricated to stringent plug gauge tolerances; accurate fit-up for GTAW root welding and orbital GTAW welding is readily achieved.

The maximum length of horizontally-spun tubes/pipes depends on diameter and wall thickness but from many producers 4/5m lengths are available in diameters from 100mm to 600mm and in some cases, even longer (6m) pipes are produced.

Horizontal centrifugal casting can be adapted to cast an integral flange on long tubes (or an *upset* for making a screwed-tube joint); two single flanged tubes can be welded to give long flanged spools. (see *Figure 17.)*

Pipe fittings such as weld neck flanges, extended flanged nozzles, tees and reducers are rapidly produced by verticle centrifugal casting. *(Figure 2) (Figure 3b)*

Whereas for high temperature applications of centrifugally-cast pipe in heat-resisting austenitic alloys for petrochemical furnaces, heat-treatment is not normally applied for corrosion-resisting applications, centrifugally-cast pipe and fittings in corrosion-resistant alloys must normally be heat-treated to confer optimum corrosion resistance. The optimum heat treatment depends on the alloy, but for austenitic steels and nickel alloys it generally involves a solution-quench anneal; in the case of some alloys, e.g. cast Alloy 825, a second thermal stabilization heat treatment at about 940°C is recomended to obtain the best combination of corrosion resistance and strength.

For most practical purposes, the general corrosion resistance of properly heat treated centrifugally-cast austentic and duplex stainless steels in the type of anaerobic enviroment encountered in the oil and gas production can be regarded as being of the same order as wrought equivalents. However, there is evidence that increasing grain size has a strong negetive effect on hydrogen embrittlement/sulphide stress cracking resistance of ferritic, martensitic and duplex stainless steels. Consequently, in assessing the suitability of such steels in centricast form for severe sour service or where cathodic charging of hydrogen may occur as in cathodically protected installations, the higher grain size of centrifugally-cast steels compared with their wrought equivalents should be taken into account and specific test data on the centricast alloy referred to.

In the case of cast medium and high-nickel alloys there have been frequent references in corrosion literature to cases where static castings, e.g. pumps and valve bodies, have shown significantly inferior performance compared with adjacent wrought piping of corresponding composition, particularly in very aggressive chemical industry acid environments. Many such cases refer to ACI-CN-7M, a relativley high-carbon, unstabilized Alloy 20 but some also refer to higher nickel alloys such as CW 12WM, a standard cast Alloy C type material which until recently has not been subjected to the evolutionary developments that have markedly benefitted the corresponding wrought grades. Incorrect or ineffective heat treatment is responsible for some of these cases while others result from bad casting quality, e.g. sand inclusions, gas porosity and shrinkage porosity. However, many of the current standard cast corrosion-resistant alloys are just direct cast versions or early corresponding wrought alloys instead of being specifically formulated to give an optimum combination of corrosion resistance, mechanical properties, castability and weldability.

In *Section 4* of this paper, reference is made to the development of a specific cast Alloy 825 specification which has been successfully used for heavy wall centrifugally-cast manifolds on North Sea platforms; Huey test data on this alloy indicate the resistance to intergranular corrosion is comparable to that for wrought Alloy 825.

Gossett *(Reference 2)* reviews improved versions of CN-7M and cast Alloy C from corrosion resistance and weldability standpoints, particularly in the context of static and castings.

Centrifugal castings, because of their intrinsic cleanliness, generally show better corrosion performance than that of static castings but nevertheless there is a need to incorporate information available on optimum composition ranges, process variables and heat treatment into national and international specifications for centrifugally-cast corrosion-resistant alloy pipe and fittings.

2. PRODUCTION OF PIPE FITTINGS FROM CENTRICAST STOCK

Fittings such as elbows, reducers and tees can be made from centrifugal-cast pipe stock by normal hot-forming techniques in some alloys, and in some cases, cold-forming techniques for tee and elbow manufacture have been successfully applied. *Figure 4* shows fittings forged from centifugally-cast billets in stainless steel. Induction bending can be applied to centricast tubes in a range of materials: *Figure 15* shows Christmas tree flow loops in centricast CA6NM (UNS J91540) 13 Cr/4 Mo high-strength martenistic stainless steel tube, formed by induction bending techniques.

Attempts to produce multibranched manifold sections in a duplex stainless by *hot extrusion* techniques have not, to date, been successful. However, tees in this material are readily produced from centricast pipe stock.

Centrifugal-cast billets can be used as feedstock for production of wrought tube by extrusion, hot and cold pilgering methods.

3. PRODUCTION OF BIMETALLIC (INTERNALLY CLAD) PIPE BY CENTRIFUGAL CASTING TECHNIQUES

Horizontal centrifugal casting has been adapted to the production of internally-clad pipe which is finding increasing use in oil and gas production. It is not, however, a particularly new technology. Steel cylinders lined with abrasion-resistant materials and bearing bushes lined with antifriction materials have been centricast for many years and petrochemical reformer tubes in 35 Ni/25 Cr/Nb alloy with an external 6mm layer of 50 Cr/50 Ni/Nb alloy to resist fuel ash corrosion were in use at least a decade ago. In the last few years, however, application of centricast clad pipe with corrosion-resistant clad layers has been developed, particularly in oil and gas production and geothermal processing and, with growing emphasis on subsea completions, interest in clad piping for subsea manifolds is increasing rapidly. One of the factors stimulating this interest is the availability of clad fittings such as bends produced by induction bending and forged tees, at least in some alloy combinations. Since valves, weld neck flanges and some sizes of tees can be readily internally clad by modern weld overlaying techniques, all major components for totally clad piping systems for at least some of the clad/base metal combinations listed in *Table 1* are available.

Basically, centricast clad pipe is produced by casting the outer steel shell, putting a molten slag into the shell and then pouring the alloy layer through the molten slag. After any required heat treatment, the clad tubes are then pull-bored internally to a definite ID.

Because the clad pipe is bore machined it does mean that the accurate fit-up, vitally important for single side welding of clad pipe, can be readily achieved. Centricast clad pipe is normally available in the OD range 100-400mm; typical lengths are 4m but this is dependent on diameter and longer lengths have been produced at diameters 8" and higher.

Figure 5 is a photograph of 6" OD API 5L-X645 pipe internally clad with 3mm of Alloy 625.

Single side welds in internally-clad pipe can be made by adapting one of two basic procedures:

1) A root is prepared entirely of a clad layer, which is welded by GTAW using a filler of matching or over-matching corrosion resistance. A GTAW reinforcing bead may be added and the joint then completed with SMAW using alloy electrodes suitable for dissimilar welding. With clad alloys such as Alloy 625, C276, the weld metal would match the clad layer. In other cases, overmatching filler (e.g. 625) would be used.

2) The weld preparation and welding the root are the same as method (1). A buffer layer of low C iron is applied on top of the root weld. The weld is then completed using C steel consumables.

Generally, Method 1 is preferred.

Figure 6 is a macrophotograph of weld procedure qualification side bend test specimens for a weld in the material illustrated in *Figure 5*, and using Method 1 above. The weld is made with GTAW welding with ER NiCrMo 3 filler wire with the remainder of the joint completed by SMAW welding with E NiCrMo 3 electrodes.

Figure 7 shows a selection of a clad tee manufactured by cold forming centricast clad piping (X52 base - CF3M clad layer).

Small-diameter wrought clad pipe can be produced by pilgering larger diameter centricast clad pipe. 1" OD clad tube (X52 with Alloy 825 clad layer) has been made by reducing 4" OD centricast feedstock.

Figure 8 shows approximate cost comparisons between solid centricast Alloy 825 pipe and centricast bimetallic pipe (X65 + 3mm of Alloy 825).

4. MECHANICAL PROPERTY – DESIGN CODE CONSIDERATIONS

Although it is generally accepted that centrifugally-cast pipe will usually meet higher minimum UTS and 0.2% proof strength requirements than a corresponding static casting, this, with a few exceptions, is not taken into account in codes and specifications – (cf.ASTM A451 and A743/744). This may change when more specific standards for centrifugally-cast pipe are available for various materials. In ANSI/ASME *B31.3–Code for pressure piping: Chemical Plant and Petroleum Refinery Piping*, which is the code currently most widely used for process piping on offshore platforms or onshore processing installation, no particular account is generally taken of the high degree of soundness inherent in centrifugally-cast pipe when, as is the normal practice, the bore is machined. This machining removes the shallow interdendritic porosity confined to the immediate bore which is characteristic of as-cast centrifugal castings. In ANSI/ASME B31.3 a casting factor Ec of 0.8 is applied in computing maximum allowable design stresses, irrespective of whether the casting is a complex static casting or a simple centrifugal-cast pipe or cylinder.

This factor Ec can be progressively increased to 1.0 (see *Table 2)* for both static and centrifugal castings by machining all surfaces, applying dye-penetrant testing to all surfaces and either 100% radiographic or ultrasonic testing.

Ultrasonic testing is not realistically applicable to cast austentic alloys so in order to obtain an Ec of 1.0 centrifugally-cast pipe must be fully radiographed. Experience shows that with centrifugally-cast pipe machined inside and out and dye-penetrant tested to confirm the bore microshrinkage has been completely removed is, if anything, less likely to have below surface defects than wrought pipes; the latter can have laminations for example, which may remain undetected until the pipe is cut up and prepared for welding fabrication and at worst may be manifest as lamellar tearing in subsequent inspections of welded-on branches etc. In spite of the high degree of internal soundness inherent in centrifugal castings, because of characteristic solidification mode, fully machined pipe, tested by DPI to show complete freedom from surface defects, still suffers a 10% penalty in design stress, unless the pipe is 100% radiographed.

In the case of the cast austentic grades CPF3 and CPF3M, the 10% loss due to a 0.9% Ec is largely compensated, in comparison to equivalent wrought grades, by higher allowable stress values.

Each indivdual wrought alloy/cast equivalent comparison has to be considered on its merits. This will be illustrated with reference to the four classes of cast and wrought materials:–

(i) Cast austenitic stainless steel vs wrought equivalents e.g. CPF3:3M vs 304L:316L.
(ii) Cast duplex steels vs wrought duplex stainless steels.
(iii) Cast Alloy 825 vs Wrought Alloy 825.
(iv) Cast Alloy 625 vs Wrought Alloy 625.

(i) AUSTENITIC STEELS

Table 3A compares the minimum ASTM specification properties and ANSI/ASME B31.3 design stresses for 304L and 316L and their cast equivalents, ASTM A451–CF3 and CF3M respectively. In spite of the fact that no distinction is made in the specification between static and centrifugal castings, the cast steel properties and resultant ANSI 31.3 design stresses are usually higher than the corresponding wrought alloys at the design temperatures (circa 250°F) likely to be considered in topside process piping on offshore platforms. This, in practice, largely offsets the penalty applied to cast pipe (10%) if 100% radiography is not carried out.

In mid-1988, API Specification 5LC covering *Corrosion-Resisting Alloy Line Pipe* was issued. Centrifugal casting is an acceptable pipe production method in this specification and the minimum property requirements for Grade LC-30-1812 for 3161-/CF3M type piping are the same as those given for CF3M in *Table 3a*.

(ii) DUPLEX STAINLESS STEELS

In April 1987, an ASTM Specification A872-87, *Centrifugally Cast Ferritic/Austenitic Stainless Steel Pipe,* covering one 22% Cr grade (UNS J93183) and one 25% Cr grade (UNS J93550), was issued.

As shown in *Table 3,* the 22% Cr grade (UNS J93183) steel is directly comparable in minimum properties to those of the corresponding wrought grade A790 (UNS S31803) now extensively used in oil and gas production and in consequence ANSI/ASME B31.3 maximum allowable design stresses are the same for both forms.

In the case of the 25% Cr grade (UNS J93550) the minimum properties stated in A872 are identical to those for the 22% Cr grade which does not reflect the fact that the higher Cr grades are generally stronger than the 22% Cr grade.

In Europe, before the introduction of A872, centrifugally-cast pipe in UNS J93550 type alloys was regularly made to 100,000 psi UTS minimum, compared with 90,000 in A872. The corresponding wrought grade to A872 (UNS J93550) is A790 UNS S31260 which has 100,000mm UTS. As shown in *Table 3b,* centricast pipes to A872 – J93550 are, in consequence, accorded a lower minimum allowable design value than the equivalent wrought grade. On the basis of general European experience, penalizing the centricast form in this way is, perhaps, not justified. In Europe some high Cr, high N modifications of J93550, designed to give maximum corrosion resistance (Zeron 100*, Fermanel*), have also high strength in both centricast and wrought forms.

API Specifications 5LC–*CRA Line* Pipe, accepts centrifugal casting as a production route and covers two types of duplex stainless steel – Grade LC-65-2205 (S31803/J93183) and Grade LC-65-2506 (S31260/J93550). The property requirements for the 22% Cr grade are the same as required by A872 and A790 for cast and wrought pipe. For the 25% Cr grade the minimum UTS requirement at 95,000 psi is midway between that for A872 (J93550) and A790 (S31260).

(iii) ALLOY 825

Cast Alloy 825 differs from wrought Alloy 825 on two counts:

(a) The cast alloy is niobium stabilized whereas the wrought alloy is Ti stabilized. This is because Ti is not a particularly desirable addition element for castings. Niobium has benefits as a cast Alloy 825 addition element in the context of weldability.

(b)Wrought Alloy 825 pipe and plate for welded pipe manufacture are normally given a thermal stabilizing mill anneal at about 900-920°C where cast Alloy 825 is normally solution treated at 1150-1200°C followed by a thermal stabilizing anneal at 920-940°C.

Table 3C compares the minimum proof and UTS properties of centricast Alloy 825 with those of welded Alloy 825 pipe (ASTM B705) and hot finished Alloy 825 tube and pipe (ASTM B423).

There is no ASTM specification for Alloy 825 centrifugally-cast pipe at present but the minimum values in *Table 3c* are justified by data from mechanical property tests on 54 heats from three foundries.

These data, obtained on the basis of four precontract commercial trial heats and fifty commercial heats in the production of the manifolds depicted in *Figure 10,* are presented in histogram *Figure 9.*

It will be seen from *Table 3c* that the cast alloy pipe matches the minimum proof of B705 welded pipe and is higher than that for B423 seamless wrought pipe and tube. The minimum UTS of the cast Alloy 825 pipe matches that of the B423 seamless pipe. However, in the ANSI/ASME B31.3 *Piping Code* and the Norwegian *Piping Code* TBK6, the criteria for determining maximum allowable design stresses in such cases are such that the 0.2% proof strength is the controlling factor for materials having low proof strength/ UTS ratios such as Alloy 825.

Consequently centrifugally-cast Alloy 825 pipe, heat treated as above, could be considered on a par with B705 welded pipe as far as design stresses to ANSI/ASME B31.3 are concerned and exhibit advantage over seamless hot-finished Alloy 825 tube to ASTM B423.

API Specification 5LC-CRA line pipe covers Alloy 825 pipe and theoretically centricast pipe is acceptable in this specification. However, the composition requirements in this specification are those for wrought material, i.e. titanium-stabilized material. As referred to earlier, a niobium-stabilized

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version is desirable for castings for reasons of casting quality and weldability.

(iv) ALLOY 625

Alloy 625 is one alloy where the centricast pipe form has significantly lower strength and hence lower allowable design stress values than wrought pipe, particularly when cast pipe is compared with ASTM B705 welded pipe and ASTM B444 Grade 1 seamless pipe *(Table 3d)*. This is partially explained by the fact that the centricast pipe is normally supplied in the solution-treated condition, whereas ASTM B705 and ASTM B444 Grade 1 pipe are mill-annealed.

The minimum guaranteed 0.2% proof strength of centricast Alloy 625 matches that of B444 Grade 2 which is also solution annealed, but the UTS is considerably lower. Because of the relatively low UTS of cast pipe, its allowable design stress to ANSI B31.3 is based on UTS whereas for B444 Grade 2 the design stress is 0.2% proof strength-controlled resulting in a higher value for wrought pipe.

Of course, where Alloy 625 is used for the internal layer for clad pipe, the strength factor does not apply since most codes neglect the clad layer in design calculations.

5. REVIEW OF CURRENT APPLICATIONS

Although centrifugal casting has been used for a number of years for making barrel pump bodies, lined cylinders, pump wear rings and seawater pump rising mains in aluminum bronze, the first major application of centrifugally-cast pipe in oilfield service was probably the use in the early Eighties of about 9km of 8" Schedule 120 centrifugally-cast flowlines in 13% Cr steel for a gas gathering system in the Arun gasfield, northern Sumatra, followed by a smaller one in Algeria.

The significant applications of centrifugally-cast pipe in the North Sea oilfields which came to the author's attention in 1983/4 (excluding aluminum bronze pump rising main spools) were for 24" heavy wall pipe in 19/10/Nb (CF8C) UNS J92710 stainless steel for manifold and pipe systems in gas condensate service on a Norwegian sector platform and 6" 22/5/3 N duplex stainless steel (UNS J93183) pipe for the construction of a subsea manifold in the United Kingdom sector.

Since that time, usage in the North Sea has developed to include alloy topside manifolds on oil and gas platforms, general alloy heavy wall piping spools and more recently, centrifugallycast clad pipe for a subsea manifold currently under construction.

This and other applications, which indicate steadily growing acceptance of centrifugally-cast pipe in oil and gas production, will be briefly described.

(a) Production and test manifolds

On a number of oil and gas platforms in the United Kingdom sector of the North Sea, wrought Alloy 825 has been extensively used for process piping between the well and the oil/gas/water separators – where justified by consideration of detailed corrosion/erosion conditions, e.g. fluid temperature, velocity and flow regime, CO_2, H_2S water and chloride content, pH, etc.

On one oil platform and one southern North Sea gas platform, centrifugally-cast heavy wall pipe in Alloy 825 was successfully used with significant economic practical and delivery benefits over manifolds fabricated from seamless or welded heavy wall pipes.

Figure 10(a) shows 10" test manifolds (32mm wall) and 16" production manifolds (32mm wall) and 16" production manifolds (22mm wall) fabricated from centrifugally-cast run pipe and forged set-on branch fittings and Grayloc flanges for a North Sea oil platform.

Figure 10(b) illustrates one of the two 16" production manifolds fabricated from centrifugally-cast run pipe (38mm), forged set-in swept branches and flanges for a gas platform in the southern North Sea.

The difference in construction methods is illustrated quite clearly by the insert pictures in *Figures* 10(a) and *10(b)*. Since cast austenitic alloys are not really amendable to ultrasonic examination for critical defect detection, and radiography of set-on branch welds is not really practicable, some end users require the form of construction depicted in *Figure 10(b)* to facilitate radiographic examination of the branch attachment welds. In the case of the manifolds illustrated in *Figure 10(a)*, the Ec factor was 0.9 whereas for the case illustrated in 10(b), the Ec factor was 1.0, the run pipe being 100% radiographed. In both cases welding consumables with overmatching corrosion resistance and strength were used (AWS - ER NiCrMo3 + E NiCrMo3). Since the manifolds shown in *Figure 10(b)* were to be pigged, stringent plug gauge tolerances were stipulated. The relatively tight tolerances on ID and roundness obtained on a bore-machined cast pipe were particularly advantageous to the fabricator in achieving tight plug-gauge tolerances for the finished manifolds.

Topside production manifolds usually only require relatively short total lengths of heavy wall piping (e.g. 30-100m) and when specified in wrought special alloys can sometimes introduce procurement problems since production of small runs of specials can be disruptive to wrought pipe mill production schedules and delivery may be protracted. Furthermore, manifolds are usually specified for relatively early delivery in the construction program and the time available for materials procurement and fabrication is often severely restricted. In this context the flexibility of a centrifugally-cast alloy pipe foundry can be advantageous in the case of short procurement lead times or emergency purchasing.

The tight tolerances to which cast alloy heavy wall pipe can be produced, because of machining being an inherent part of production, may result in benefits in design, fabrication and weight control; these factors combine with cost and delivery factors to make consideration of centricast alloy pipe worthwhile for heavy alloy manifold construction.

Centrifugally-cast alloy manifolds are currently under consideration for other North Sea projects in solid Alloy 825 or in Alloy 825 clad steel.

(b) Flowlines

Figure 11 shows part of the flowline system fabricated from about 9,000m 8" Sched 120 centrifugally-cast 13% Cr martenistic stainless steel in a gas gathering system in Indonesia handling wet gas containing 13-15% CO_2, 50-100 ppm H_2S, with well pressures and temperatures of 45,000 psi and 190°C respectively. This application and its metallurgical background is described as in some detail by Matsui et al *(Reference 3)*. Smaller quantities of centricast 13% Cr are also used in an Algerian natural gasfield.

This steel has good resistance to corrosion/erosion by wet CO_2 but may in some circumstances be susceptible to sulphide stress corrosion cracking when even small amounts of H_2S are present. In this case strict control on hardness of pipe and weld zones was maintained to circumvent SSC. Centrifugally-cast duplex stainless (J93183) has somewhat better tolerance for H_2S and is now under consideration for this type of application and has, in fact, been used for flowlines in geothermal facilities, where corrosion considerations generally have close similarities with those for wet sour gas.

Centricast X60 flowlines lined with CF3M stainless have been used in geothermal service in the United States and where more severe corrosive flowline service is apparent, centrifugally-cast clad pipe with nickel alloy lining comes into reckoning. For example X60 piping clad with 2mm of C276, produced by centricasting is being used by an oil company in the US for geothermal flowlines while another US oil company is evaluating centricast Alloy 625-clad sour gas flowlines.

(c) Subsea manifolds

In 1984, centrifugally-cast 22/5/3 duplex stainles steel (UNS J93183) was used for the construction of a subsea manifold in the UK sector of the North Sea. This is illustrated in *Figure 12*. One consideration which has to be taken into account in the use of duplex steel in subsea applications; irrespective of whether the material is wrought or cast, is the possibility of cathodically charging the steel with hydrogen and consequent embrittlement if cathodic protection at high negative potentials is applied. This might occur for example if the carbon steel supporting structure was protected at the normal carbon steel protection potential and was in electrical contact with duplex steel.

Such considerations, however, do not apply to another case in the UK sector of the North Sea where 6" centrifugally-cast bimetal pipe is being used currently in the construction of manifold piping for a subsea template. *(Figure 13 a & b)*. For the straight run pipe, centricast bimetallic pipe with X-52 backing steel and 3mm minimum internal cladding of Alloy 625 is utilized; the tees are in solid Alloy 625 and the weld neck flanges are in forged carbon steel, overlaid in the bore and on the flange face and groove with Alloy 625 using synergic pulsed MIG deposition techniques. It is understood that this bimetallic centricast pipe approach is under consideration for at least one other subsea manifold in the UK sector.

(d) Christmas tree piping

Centrifugally-cast small-diameter pipe in CA6NM (13 Cr/4 Ni/Mo) (UNS J91540) martensitic stainless steel has been used for Christmas tree piping for a number of North Sea projects. *Figure 14* shows flow loops fabricated from induction-bent CA6NM pipes and other spools in the same material undergoing local postweld heat treatment, and *Figure 15* shows some of these spools in position on a subsea tree. Specific attention has to be given to the two-stage postweld temperature heat treatment necessary to meet the hardness requirements of NACE MR 0175.

Flow loops for subsea Christmas trees have been produced in centricast bimetal pipe (X52 and Alloy 625 cladding) in connection with the subsea production project referred to in the previous section.

(e) Seawater pump rising main spools

Centrifugal-casting of spools for service of seawater pump rising mains on offshore platforms has been an established production route for several years. Such components have generally been produced in nickel aluminum bronzes (e.g. UNS C95500, UNS C95800) but some consideration has been given to producing pump columns in centricast versions of proprietary 6% Mo stainless steels. The technique, referred to earlier, of producing flanged spools by joining two *half-spool* centricastings, each having an integral cast flange, has been widely used in practice. *Figure 16* shows automatic production welding of centricast nickel aluminum bronze pump column spools; GTAW welding with helium shielding gas and GMAW welding with argon-helium mixtures are preferred procedures for joining such components. There have been recorded service failures of aluminum bronze pump riser spools fabricated from plate owing to *de-aluminification* of the weld zone, the spools splitting open along the longitudinal welds due to severe reduction in strength of the weld zone. It should be noted that this phenomena is well known in welded aluminum bronze castings *(Reference 4)*. The susceptability of welded aluminum bronze to de-aluminification can be markedly reduced by heat treatment and this is strongly recommended for centricast aluminum bronze spools. The normal heat treatment, which is 6 hours at 675-715°C, can be readily applied to the circumferential welds in the centricast spools by local heat treatment using electrical resistance heating.

General pipe spool fabrication

Figure 17 shows some of the heavy wall pipe in centrifugally-cast CF3M (316L equivalent) pipe consignment depicted in *Figure 1*, fabricated into pipe spools in conjunction with normal wrought fittings for a recently constructed platform in the UK sector. This was free issue by the project management team as part of 316L material packages to pipe spool subcontractors who were generally unaware of any difference in form of supply. *Figure 18* shows a number of spools in centricast Alloy 825 with cast fittings and sweep bends produced by induction bending of centricast pipe for a project in China.

MISCELLANEOUS APPLICATIONS

Barrel pump bodies

Barrel pumps are generally, though not exclusively, used for injection of deaerated seawater in the North Sea. Barrel pump bodies are conveniently fabricated from a vertically centrispun barrel and vertically spun nozzles with integral flanges, which are then welded into the barrel *(Figure 2)*. For some of the earlier projects, 316L water injection pumps were used but for a number of years 25/5/Mo duplex stainless steel pumps (J93255) have become standard; proprietary versions with higher Cr, Ni, N, Mo contents are now being used.

Pump wear rings

Centrifugal cast stock is an obvious suitable starting stock for the production of pumpwear rings in a wide range of materials, including Ni-Cr-Mn-N steels, nickel-copper aluminum alloys, nickel-base alloys, austenitic and duplex stainless steels, etc.

Ball valve balls

Centrispinning is an excellent way of producing balls for ball valves, mainly in stainless steel CF3M. See *Figure 3*. Most foundries produce the component by vertical spinning, though at least one has developed a horizontal spinning technique, for small-diameter balls.

CONCLUSIONS

(a) During the past five years a significant number of varied applications of centricast alloy pipe and pipe fittings indicates opportunities where, from technical, availability and cost considerations, centricast products may provide a viable approach in piping selection. This viability becomes most evident for heavy wall pipe.

(b) Some current codes of practice, e.g. ANSI B31.3, do not acknowledge any difference between centricast pipe and static castings of varied complexity and section in assigning minimum strengths for design value computation and in soundness (cf Quality Factor Ec) whereas experience suggests differently. A 100% radiographic requirement of centricast pipe in order to raise the casting quality (Ec) from 0.9 to 1.0 is considered rather stringent for large pipe orders in austenitic materials which cannot be ultrasonically tested, particularly when consideration is taken of the fact that by its very nature, centricast pipe – bored, skimmed and DP tested (Ec 0.9 – has an extremely low propensity to internal defects in the wall of the pipe.

Relaxation of this requirement, say, to random spot radiography as a quality control measure, could further improve the economics of cast pipe.

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Firth Vickers Foundry Ltd, United Kingdom
Pose-Marre Edelstahilwerke GmbH, West Germany
Manoir Industries, France
Kubota Ltd, Japan
Schmidt and Clemens GmbH & Co., West Germany
Spun Alloys, United Kingdom

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2. J.L.Gossett — *New and improved high-nickel alloy castings.* NACE Corrosion '88, paper 322

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Table 1

Backing steel	Clad layer
API–5L– X65) X60) – X52)	CF3M stainless steel Alloy C276 Alloy 825 Duplex stainless steel (UNS J93183, J93550) Alloy 625

Centricast bimetallic pipe combinations of interest in oil and gas production.

Table 2
ANSI B31.3 code for pressure piping – chemical plant and refinery piping.
Basic casting quality factor for centrifugal-cast pipe (Ec) = 0.8.
Increased casting quality factors for supplementary quality control.

		Ec
(a)	Machine all surfaces to specified standard	0.85
(b)	Apply MPI to magnetic materials or DPI to nonmagnetic materials	0.85
(c)	Machine as in (a) and MPI or DPI as in (b)	0.90
(d)	Radiograph or UST 100%	0.95
(e)	Machine as in (a) and radiograph or UST as in (d)	1.00
(f)	DPI or MPI as in (b) and radiograph or UST as in (d)	1.00

Increased casting quality factor Ec for supplementary quality control.

Table 3a
Comparison of strength and ANSI B31.3 design values for wrought vs cast austenitic steels

Alloy designation	Normal composition	ASTM specification	Specified minimum properties					ANSI B31.3			Design stresses KSI			
			UTS		Proof (0.2%)		Elong^{n}	Up to 100°F	200°F	300°F	400°F	500°F	600°F	700°F
			KSI	MPA	KSI	MPA	%							
Cast alloy CPF3 (UNS J92700)	19 Cr 9 Ni 0.03 C max	A451 (A744/743) (Static)	70	485	30	205	35	20.0	20.0	19.7	17.6	16.0	15.6	15.1
Wrought alloy 304L (UNS S30403)	19 Cr 9 Ni 0.03 C max	A312 A269 A358	70	485	25	171	40	16.7	16.7	16.7	15.8	14.8	14.0	13.3
Cast alloy CPF3M (UNS J92800)	17 Cr 10 Ni 2.5 Mo 0.03 C max	A451 (A744/743) (Static)	70	485	30	205	39	20.0	18.0	17.4	16.6	16.0	15.4	14.6
Wrought alloy 316L (UNS S31603)	16 Cr 12 Ni 2.5 Mo 0.03 C max	A312 A269 A358	70	485	25	171	40	16.7	16.7	16.7	15.5	14.4	13.5	12.9

Table 3b
Comparisons of properties and ANSI 31.3 design stresses for corresponding wrought and cast duplex stainless steels

Alloy designation	Nominal composition	ASTM /API specifications	Minimum specified properties					ANSI B31.3 design stresses at temperatures up to 100°F	
			UTS		Proof strength		Elong		
			KSI	MPA	KSI	MPA	%	KSI	MPA
Centrifugally-cast 22/5/3/N duplex steel pipe (UNS J93183)	22 Cr 5 Ni 3 Mo 0.17 N 0.03 C max	A872 API 5LC LC-65 2205	90 90	620 620	65	450	25	30.0	207
Wrought 22/5/3/N duplex steel pipe (UNS S31803)	22 Cr 5 Ni 3 Mo 0.15 N 0.03 C max	A789 A790 API-5LC LC-65- 2506	90 90	620 620	65 65	450 450	25	30.0	207
Centrifugally-cast 25/5/3/N/Cu duplex steel pipe (UNS J93550)	25 Cr 6 Ni 2.5 Mo 1 Cu max 0.03 C max 0.1 N	A872 API-5LC LC-65- 2506	90 95	690 656	65 65	450 450	20 25	30.0	207
Wrought 25/5/3/N/Cu duplex steel pipe (UNS S32550)	25.5 Cr 5.5 Ni 3.4 Mo 2.0 Cu 0.18 N 0.04 C max	A789 A790	110	760	80	550	15	36.7	253
Wrought 25/6/1.5N duplex steel pipe (UNS S31200)	25 Cr 6 Ni 1.6 Mo 0.17 N 0.03 C max	A789 A790	100	690	65	450	25	33.3	230
Wrought 25/6.5/3/N (UNS 31260) pipe	25 Cr 6 Ni 3 Mo 0.5 Cu 0.2 N 0.03 C max 0.3 W	A789 A790 API-5LC LC-65- 2506	100 95	690 620	65 65	450 450	25 25	33.3	230

Table 3c
Comparison of strength and ANSI B31.3 design values for wrought Alloy 825 (UNS N08825) pipe and centrifugally-cast Alloy 825

Alloy designation	Nominal composition	ASTM specifications	Minimum specified properties				ANSI B31.3 design stress up to 100ºF	
			UTS		0.2% proof			
			KSI	MPA	KSI	MPA	KSI	MPA
Centrispun Alloy 825 (Solution treated at 1200ºC followed by annealing at 940ºC)	Ni 41 Cr 21.5 Mo 3.0 Cu 2.25 C (max) 0.04 Nb 0.9	–	75,000	520	35,000	241	23,333	160.7
Wrought Alloy 825 (UNS N08825) (Pipe welded from plate. Mill annealed)	Ni 41 Cr 21.5 Mo 3.0 Cu 2.25 C (max) 0.05 Ti 0.9	B705	85,000	586	35,000	241	23,333	160.7
Wrought Alloy 825 (UNS N08825) (Hot finished tube/pipe. Mill annealed)	Ni 41 Cr 21.5 Mo 3.0 Cu 2.25 C 0.05 Ti 0.9	B423	75,000	520	25,000	172	16,666	115

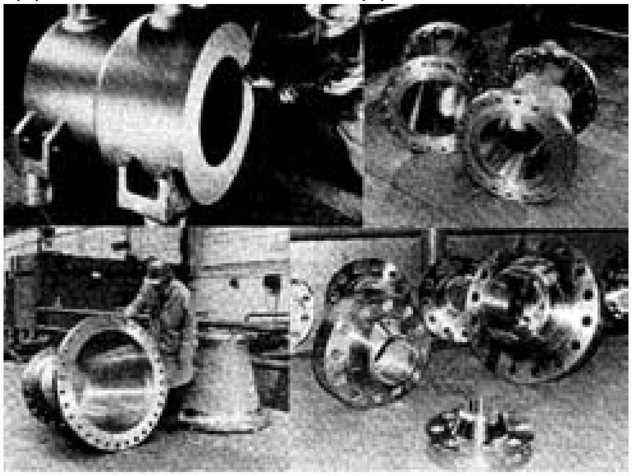
Table 3d
Comparison of strength and ANSI B31.3 design values for wrought and cast Alloy 625 pipe

Alloy	UNS N°	Minimum specified properties				Elongation, %	ANSI B31.3 design stress up to 100ºF	
		0.2% proof		UTS				
		KSI	MPA	KSI	MPA		PSI	MPA
Centricast Alloy 625* Sol. annealed	–	40	276	75	520	30 min	25.0	
Wrought Alloy 625 seamless pipe B444 Annealed – Grade 1 Sol. treated – Grade 2	UNS N06625	60 40	414 276	120 100	827 690	30 min	40 26.7	
Wrought Alloy 625 pipe (welded) AST B705	UNS N06625	60	414	120	827	30 min	40	

*Manufacturer's minimum guaranteed values

Courtesy Lake & Elliot Paramount
Figure 1 Batch of heavy wall centricast CF3M pipe destined for an offshore platform in the North Sea.

2(a) 2(b)



2(c) 2(d)

Courtesy Firth Vickers Ltd.

Figure 2 **Vertical centrifugal-cast components for oilfield service**

(a) Barrel pump body for water injection pump,fabricated from three vertical centrispinning in 25/5/2 duplex.

(b) Centrispun venturi castings in CF3M.

(c) Reducers in 25/5/2 duplex stainless.

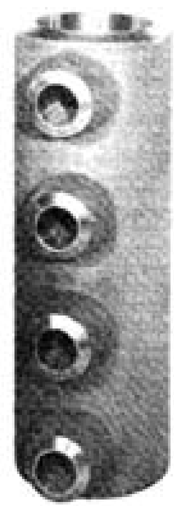
(d) Weld neck flange in duplex stainless steel.

Courtesy Schmidt and Clemens

Figure 3a Balls for ball valves, vertically centrispun in CF3M stainless steel.

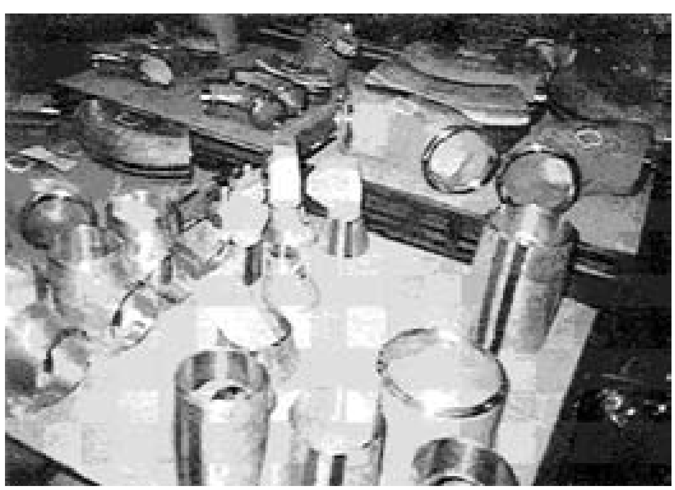
Courtesy Manoir Industries, Usine du Manior

Figure 3b Tee fitting in Alloy 625 produced by vertical spinning techniques.



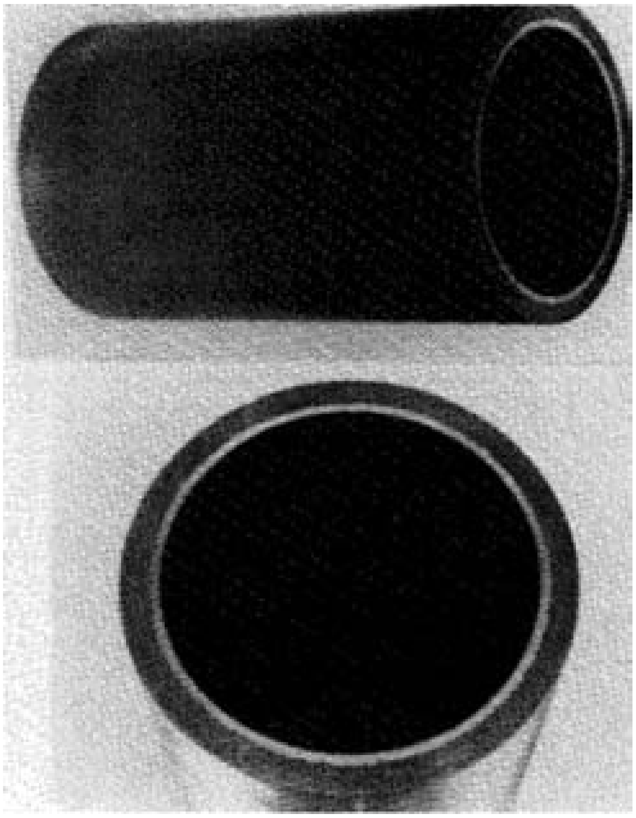
Courtesy Manior Industries

Figure 3c Manifold section with four integral outlets produced by vertical centrifugal castinq techniques.



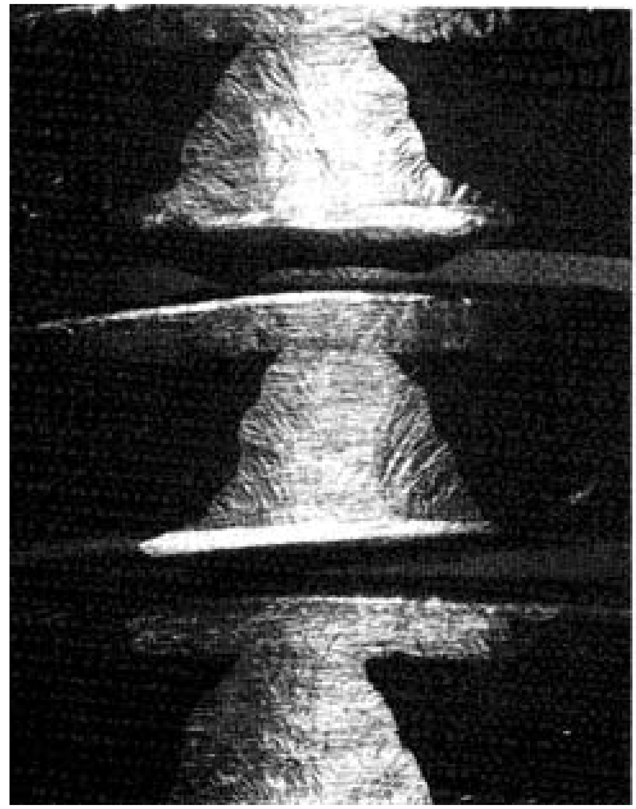
Courtesy BLK

Figure 4 Pipe fittings in high ferrite 20/10 stainless. Elbows, tees and reducers forged from centricast pipe stock.



Courtesy Kubota

Figure 5 Section of centricast bimetallic pipe. Outer pipe 6" OD. API 5L X65. Clad layer 3mm of Alloy 625.



Courtesy Scomark Engineering

Figure 6 Macrophotograph of side bends of weld made in the pipe shown in *Figure 5*. ER NiCrMo 3 filler wire and E NiCrMo 3 electrodes used throughout.

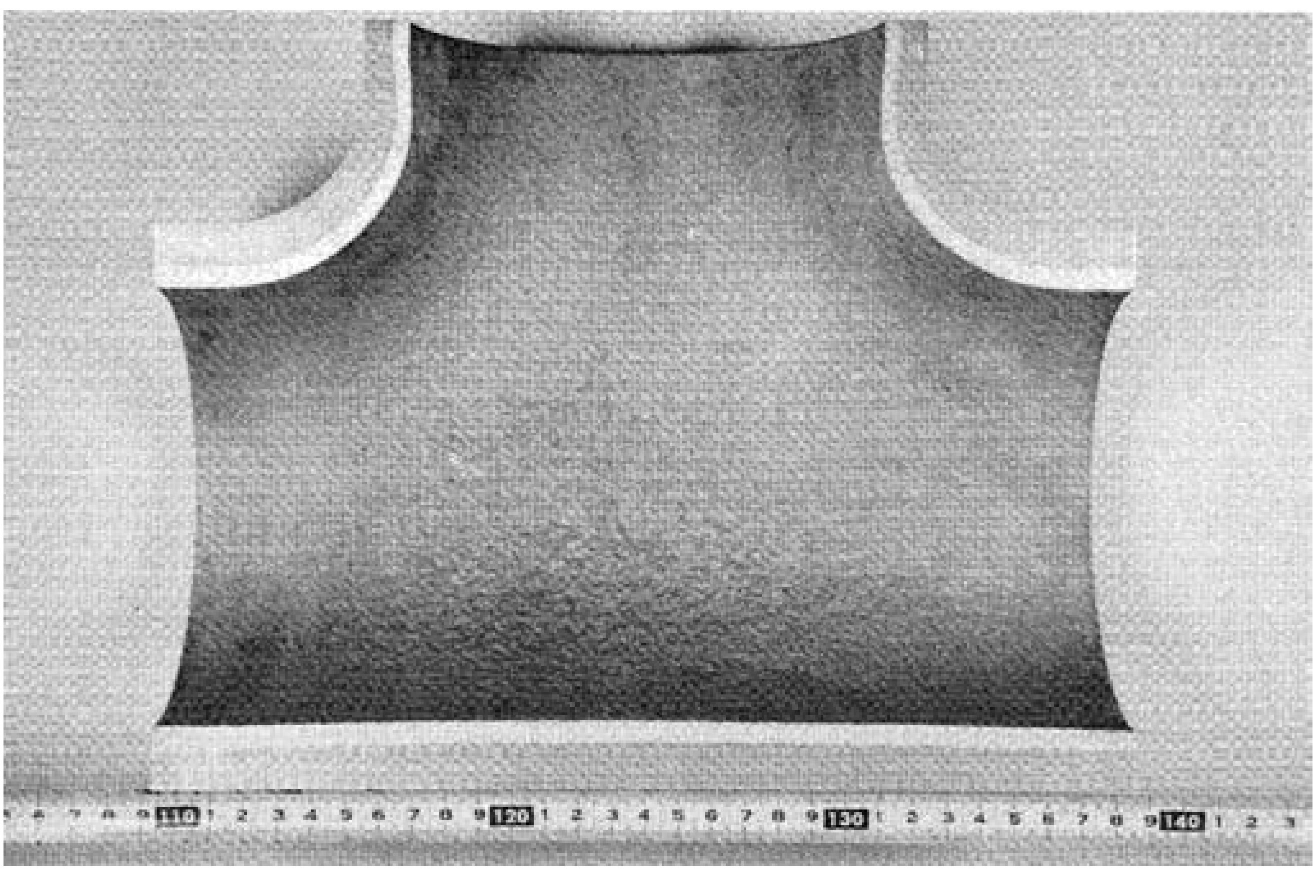
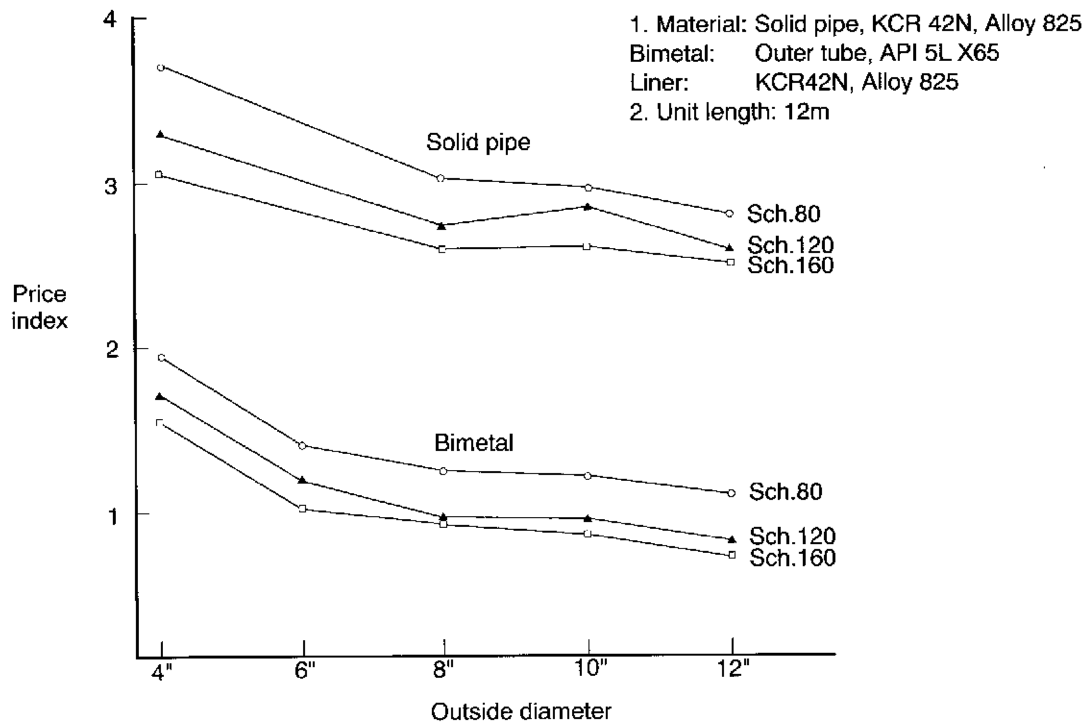


Figure 7 Section of clad tee made by cold bulge-forming of centricast bimetallic pipe (X52 base metal, CF3M clad layer).

Figure 8

Price comparison of bimetal to solid pipe (centricast), April 1986



Reproduced courtesy Kubota

Figure 9

Histrograms of 0.2% proof and UTS from 54 heats of centricast alloy 825 (temperature 20° C)

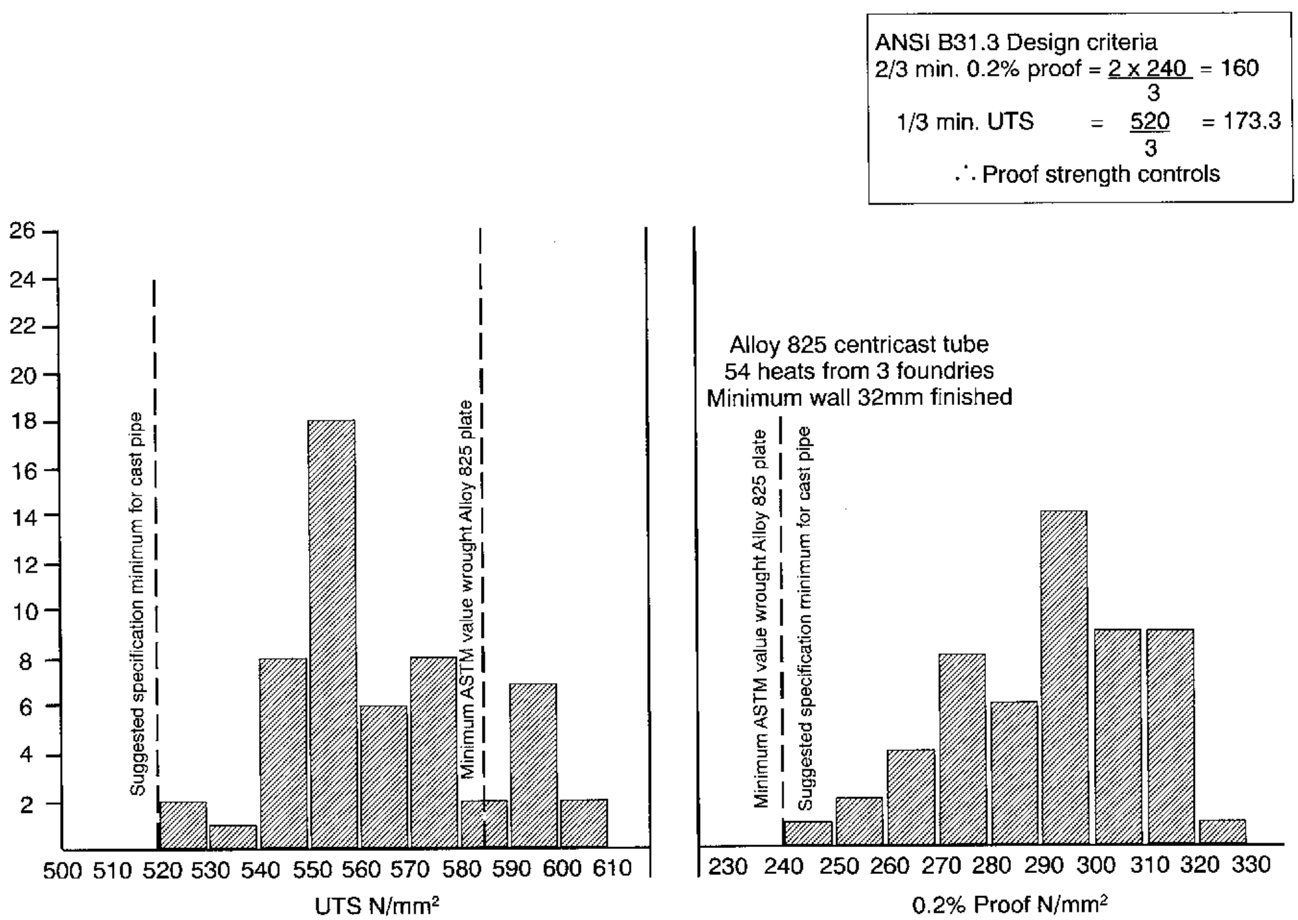
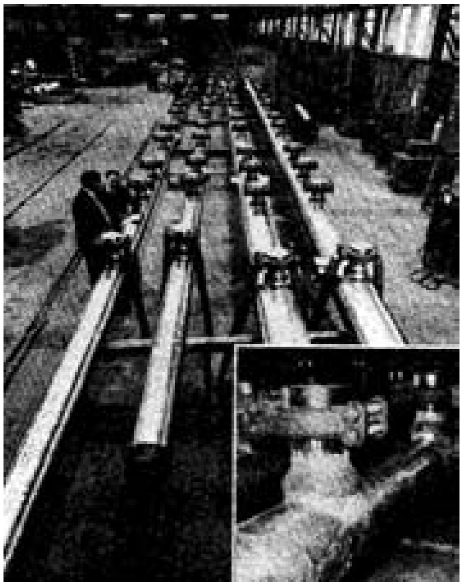
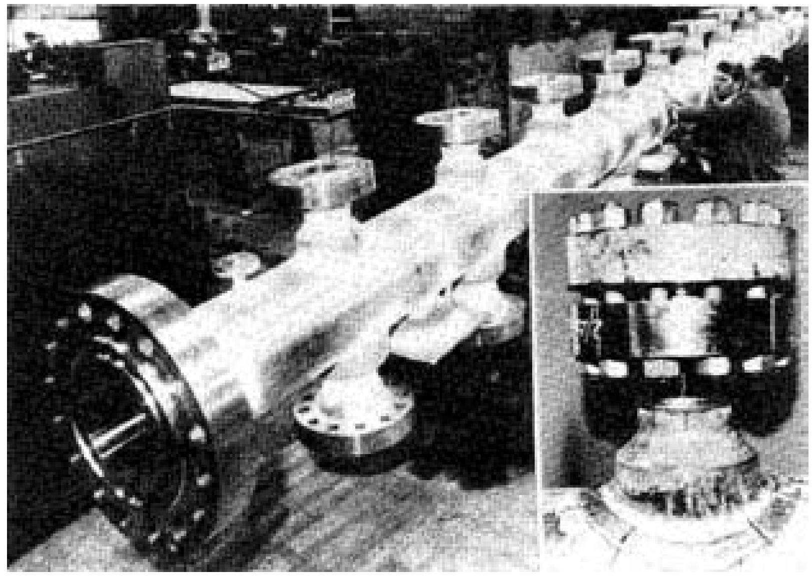


Figure 10a



Courtesy Marathon Oil U.K. Ltd.

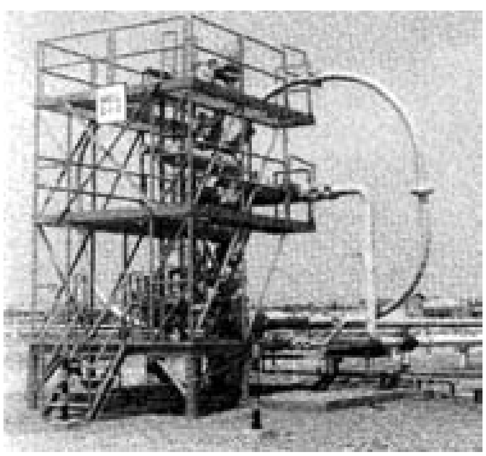
Figure 10b



Courtesy BP Petrolium Developments, Scomark Engineering

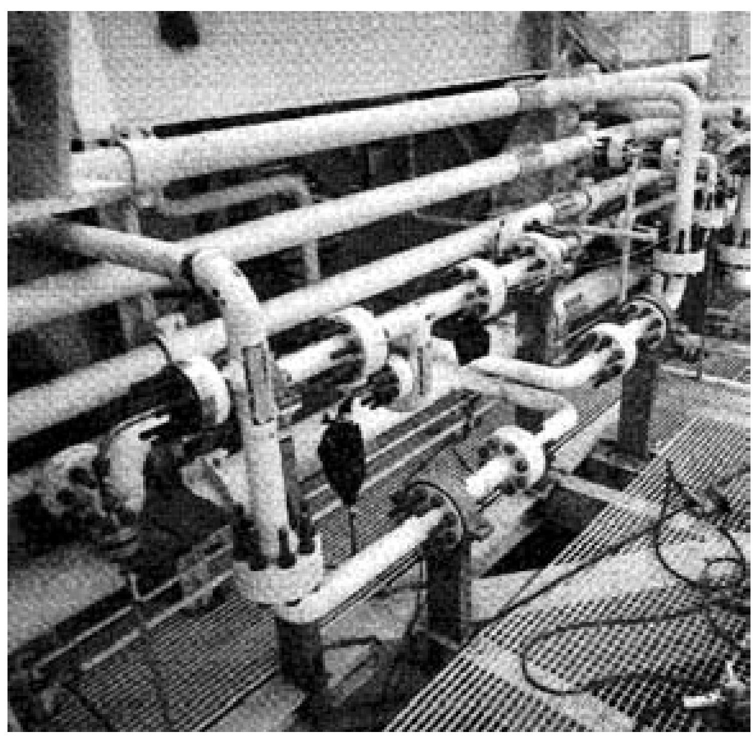
10(a) 10" x 16" production manifolds fabricated from centrifugally-cast Alloy 825 pipe for an oil production platform in the North Sea. Inset shows set-on branch construction.

10(b) One of two 16" production manifolds fabricated from centrifugally-cast Alloy 825 for a gas platform in the southern North Sea. Inset shows set-in, swept-branch construction.



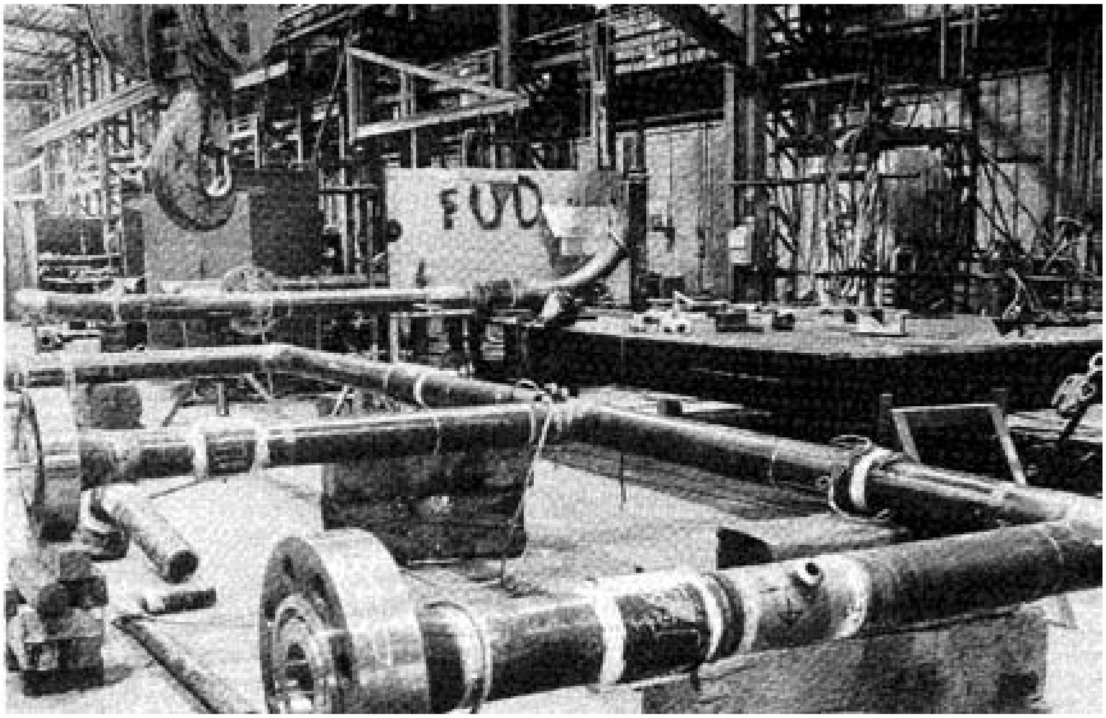
Courtesy Kubota and Mobil

Figure 11 8" flowline in centrifugally-cast 13% Cr martensitic steel in gas gathering system in Indonesia.



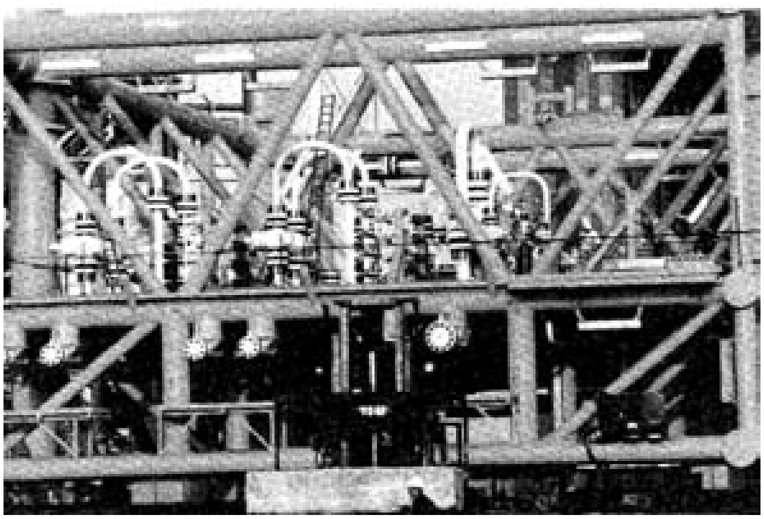
Courtesy Kubota

Figure 12 Flowline spools for geothermal plant fabricated from centricast clad pipe (X65 pipe - C276 cladding).



Courtesy Marathon Oil U.K. Ltd. and Highland Fabricators

Figure 13a Early stages of fabrication of 6" subsea template manifold centricast clad pipe. (X52 pipe – clad layer 3mm Alloy 625) for North Sea project.

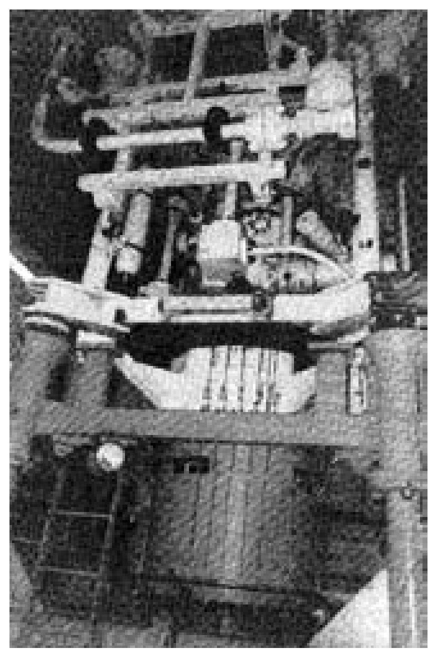


Courtesy Marathon Oil U.K. Ltd. and Highland Fbabricators

Figure 13b End view of subsea template incorporating clad piping depicted in *Figure 13a.* The production piping systems at centre and left of picture are in alloy-clad pipe.

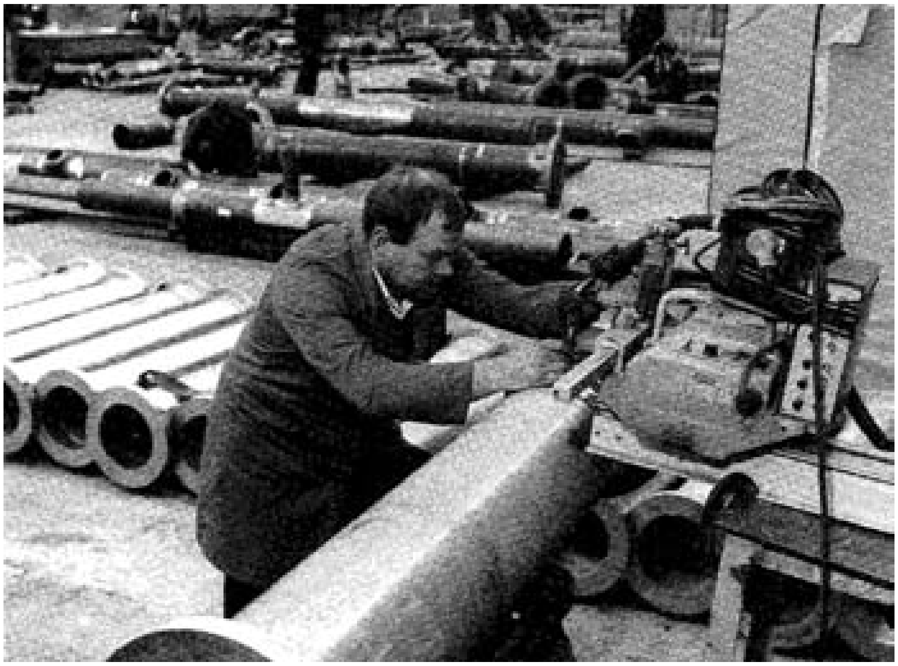
Courtesy Lahe & Elliot Paramount and Scomark Engineering

Figure 14 Christmas tree piping spools fabricated from CA6NM undergoing local postweld heat treatment.



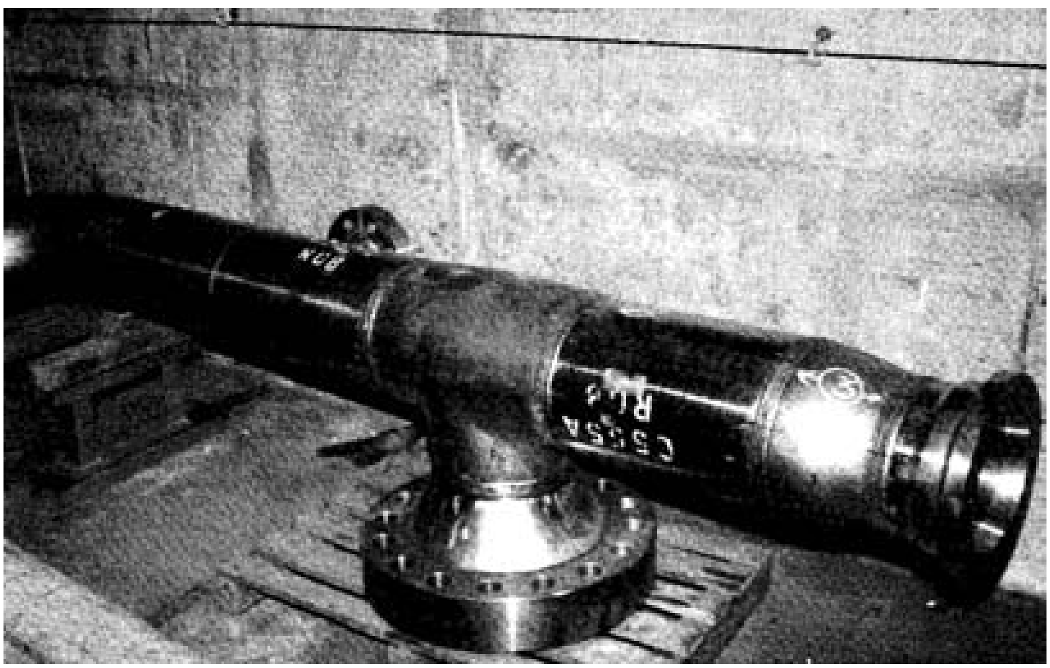
Courtesy Cameron IronWorks

Figure 15 Piping illustrated in *Figure 16* installed on tree assembly.



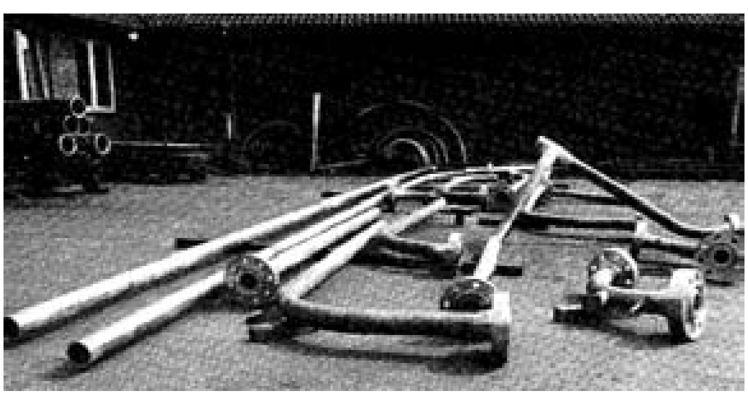
Courtesy Spunalloy Ltd. and Schomark Engineering Ltd.

Figure 16 Automatic girth welding of nickel aluminum bronze pump riser spools formed from two centricast half spools with integral flanges.



Courtesy Spunalloy Ltd. and Schomark Engineering Ltd.

Figure 17 One of a large number of 316L/CF3M pipe spools fabricated from CF3M pipe shown in *Figure 1* and wrought 316L fittings for a North Sea project.



Curtesy Schmidt and Clemens

Figure 18 Pipe spools in centricast Alloy 825 pipe with cast fittings, induction-bent sweep bends produced from centricast pipe for a project in the Far East.