ON THE ECONOMIC BENEFIT OF USING COMPONENTS INTERNALLY CLAD WITH CORROSION RESISTANT ALLOYS

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ABSTRACT

Given the highly corrosive environments which have to be **handled** in the geothermal industry and the cost benefits of reduced unscheduled downtime when CRAs are used, operating cost savings would be anticipated if **more** use was made **of CRAs.** By utilising clad products much less weight of expensive corrosion resistant alloy is needed and potential capital costs savings can be **made.** This paper describes the range **of** production routes available for manufacturing clad products and shows that it is possible to **engineer almost** any item which might **be** required in clad form. Successful application of clad products **in** other major industries over the last 40 **years** should encourage their increasing application in the geothermal industry

1. CORROSION IN THE GEOTHERMAL INDUSTRY

The **experience** of **corrosion** in geothermal wells and plants varies significantly between different locations and **wells** In general **terms,** dry steam producers are not highly **corrosive whilst** the hyper-saline producing **wells** can be severely corrosive. **Wells** producing more moderate temperature **brines are also encountered** and can **also** be corrosive

Dry systems are not corrosive but once pressure or temperature drops result in some condensation and the formation of droplets and therefore wetting of metal surfaces, corrosion **is often experienced** The Corrosion rate is related to the phase **balance** between dry **steam** and condensate **as** well **as the** pH of the condensate. The acidity of the condensed water can be very variable and values between 2.8 and 6 0 **are quoted** for different locations Droplet impingement in two phase flow systems can **also cause** severe erosion-corrosion problems. particularly at **elbows** and valves

Hypersaline geothermal **wells** may be potentially highly corrosive environments as a result of the high content of dissolved CO_2 (which **may** exceed 5,000ppm **at** 4MPa total pressure) and extremely high temperatures (typically in the region of 260°C bottomhole and 210°C **at** the wellhead). Most geothermal wells are drilled in the depth range down to about 2200m with occassional drilling to 4300m which can result in fluids having Temperatures in **excess** of 350°C. Corrosion is further exascerbated by high salinities with often over 10wt% chloride and various amounts **of** other elements which may include sulphides. lead, antimony, copper and other noble metals and silica The heavy metal ion5 which **have** a more noble redox potential than iron **(eg** Pb, Cu, **As,** Sb and Ag) **may** reduce on the metal surface and stimulate iron corrosion. **These** heavy metal ions are well-known agents for pitting initiation on **many** metals and alloys The sulphides may in certain circumstances form a protective *scale* on the metal surface but this **creates** a large cathudic area so that there is increased risk **of localised** curosion at **any** breaks in the scale **(1)** Additionally. **scalc** can grow in thickness creaiing a situation in which wellhead production **is** checked requiring pipe cleaning and / or replacement

A review ofthc curosion behaviour of materials exposed to the type of environments described **above** concluded that carbon steels and ferritic stainless steels (AISI 430 type) may **suffer** heavy general and localised corrosion (2) Acceptable resistance to corrosion **was** given by the nickel alloys such as Inconel 600. tttanium and the nickel-cobalt alloy MP35N with best performance from Alloy 825. Hastelloy C276 and 29Cr-4Mo steel

Corrosion tests on the performance of several corrosion resistant alloys (CRAs) were carried out using the actual geothermal fluids in the Salton *Sea* Resource **Area** (3) The **operating** conditions here are 215-235°C, 112,000 - 120,000ppm chlorides, pH=5 The tests indicated thai in general the stainless steels tested wcre not suitable since the ferritic alloys (e g. AISI **410)** suffered unacceptable pitting corrosion **and** the low **alloy** austenitic (including **AISI 316L) were susceptible** to **stress corrosion** cracking **Materials** which **were considered possibly** suitable **for service included Hastelloy, Inconel,** Titanium **or** concrete/polymer **pipes.** A **funher** reference to **tests at this location** ***(4)*** **suggests that** the titanium alloys **Grade 12 and Ti -** 0.15Pd would **be** particularly preferred in **cases** were oxygen entry could not **be prevented** (e g. **during brine reinjection** or **as** a result of system leaks/downtime) and temperatures were above 100°C and chloride level above 5,000ppm

From actual service **experience,** cracking of YUS 170 austenitic stainless **steel** (13%Ni-25%Cr-1%Mo and 0.3%N) was reported within two **weeks** of going into **service** indicating **a crack** growth rate **of** about 0.43mm/day. **This was replaced by YUS 190L** (19%Cr-2%Mo) (5). Similarly, in Iceland (6), a high pressure **well** (HP12) with a room **temperature** pH quoted as 2.8, 17,000ppm CO_2, 827ppm H_2S **and** 66ppm chloride produced stress corrosion cracking and **some** pitting in AISI **304** austenitic stainless steel In the same conditions mild steel corroded at more than 20mm/y and 13Cr stainless steel pitted at 0.7 to 4mm/y.

In wells where H_2S is present, low strength API **355 casings** with buttress thread joints have been accepted **as** the standard matenal following experience of **sulphide** stress cracking failures with higher strength **materials** (API N80 and P110) in New Zealand (1, 7) Tool joints **in** Larderello (38NCD4 or AISI 9840) also cracked because of the presence of H_2S during drilling **(7)**

Experience with CRA casing materials has increased at locations producing hypersaline brines Whilst in the past the carbon steel liners to the **wells** had to be hung **because** they corroded and therefore had to he retrievable, there has **been such successful use** of titanium, for example, **that** the liner is now cemented in place This has the additional benefit of reducing fatigue failures of the liners due to vibration of the string (8).

Other operating problems reported in the survey conducted in reference 9 indicate that there is quite a large unscheduled downtime experienced in geothermal plants because of materials problems Examples cited include carbon steel gate valves with electroless nickel plate coatings on the gates which failed in 5,500 hours Gates overlay welded with AISI 304L and Stellite No 6 hardfacing lasted for between 10.000 and 80,000 hours Cylindrical AISI 304 diffusers in a carbon steel muffler exposed to steam with <1ppm chlorides at 177°C cracked within 20 duty cycles Carbon steel piping with epoxy coating had a service life of 3 to 5 years carrying condensate whilst AISI 316L had been in service for more than 15 years Peralumin 30 (Al-3-4%Mg, 0 4Mn) lasted about 10 years in the same service Cooling water piping in carbon steel failed within 2 years and was replaced by AISI 316 and FRP at certain locations Pits of about 1mm depth were noted in the stainless steel after approximately 14 years service

The above review of the corrosive conditions which may prevail in geothermal systems is an indication that rather severe corrosion may arise where condensed water is present, particularly if flow conditions are turbulent In these cases correct materials selection to avoid general and localised corrosion, erosion and stress corrosion cracking will tend to require rather highly alloyed materials which are expensive. The sort of producrs which may be needed to be corrosion resistant include downhole tubulars. surface piping and components and equipment including valves and maybe other items All these products can be obtained as solid alloys but the cost may be regarded as prohibitive and therefore cheaper materials with shorter service lives are often tolerated with the inevitable downtime that is associated with the unscheduled failures as well as the need for regular inspection

An alternative materials selection which might be considered would be to utilise the expensive alloy as a thin cladding layer on a cheaper substrate (normally steel) The cladding layer is then selected to give optimum resistance to the environment whilst the backing steel provides the mechanical integrity - often offering superior strength than CRAs and thus allowing thinner walls to be used

2. CORROSION RESISTANT ALLOY (CRA) CLAD CARBON STEEL

2.1 General Aspects

The concept of carbon steel clad with a fairly thin layer (usually 2-3 mm) of CRA has been well established for vessels. separators, heat exchangers, tanks etc for more than 40 years in the chemical, petrochemical, flue gas desulphurisation and oil refining industries Over the last 20 years there has been an increase in the application of clad products, particularly pipe. in the oil and gas industry

In principle any combination of CRA cladding composition and backing steel strength can be manufactured but in practice the range of combination is limited by the need to balance the heat treatment requirements of the two metals. Most manufacturers *have a* preference for CRAs which can be solution annealed (which is necessary to optimise the corrosion properties of the CRA after hot forming operations) at fairly low temperatures - preferably below 1000 °C. Alloys which demand much higher annealing temperatures may give problems when clad to carbon steel since the backing steel may experience grain growth under these conditions resulting in a loss of strength and toughness The most widely applied cladding alloys to date have been stainless steel AISI 316L and nickel alloy 825 both of which can be annealed at 950°C Nevertheless substantial quantities of products clad with higher alloys such as alloys 625 and C276 have been produced where the application warranted it Alloy 625 has been widely applied as a corrosion resistant weld overlay on flange faces, valves and other piping components as well as for short flowlines (pipelines)

An exception to the above concerns is the use of explosive bonding or thermal shrinking *to* produce a mechanically bonded pipe. This is referred to, following the API 5LD convention, as a lined pipe rather than a clad pipe In these methods heat treatment is not required after Pipe lining because the lining material is already solution annealed before placing in the pipe and the lining processes are cold (in the case of explosive forming) or below @ 350 °C (in the case of thermal shrink-fitting)

Details of manufacturing methods of clad products and applications are summarised in Section 3 below and described in more detail in references 10 and 11

2.2 Technical and Economic Benefits

The immediate benefit of using the CRA as a cladding is that a much smaller quantity of the expensive alloy is required when compared to a solid alloy pipe

The major technical benefit when considering clad steel In place of solid alloy fur fully welded fabrications is that it is the backing steel which provides the strength, toughness and mechanical integrity of the pipeline so that the low strength of the annealed alloy layer is no longer a limitation (Most design codes actually exclude any strength contribution from the alloy layer)

A correctly selected corrosion resistant alloy would be expected to show negligible corrosion and no risk of cracking or leakage during service for the full life of the project It is notable that the field experience with clad materials across many industries is excellent with very few failures arising once they have been put into their intended service Thus. clad materials offer a level of security against unscheduled downtime with its economic consequences. A further benefit of switching frum carbon steel to Corrosion resistant alloy pipe (solid or clad) is the higher erosional velocity limit of CRAs compared to carbon steel This gives superior resistance to droplet impingement attack. erosion-corrosion and virtually eliminates scale build up

The cost saving from using clad steel rather than solid CRA is particularly valid when the total thickness increases or when the cladding alloy grade becomes more complex and hence expensive An indication of the sort of savings which can be made is illustrated for integrally bonded clad plates in Fig 1 Similar savings may be anticipated fur other clad products such as pipe and fittings For the higher alloys which geothermal conditions may demand the potential capital cost saving of using clad materials rather than solid could be very significant

It is possible to use established economic analysis methods to compare the real cost benefit of selecting fully corrosion resistant alloys (either solid or clad), which are intended to provide reliable pressure containment for the full life of a project, with less corrosion resistant materials which will need *to* be replaced with a certain frequency. In the case of materials which are known to corrode in the service environment, additional costs, beyond the initial capital outlay, are encountered to cover corrosion allowances, possible injection of chemicals to inhibit corrosion and the need for regular inspection as well as downtime periods for maintenance and planned or unscheduled replacement activities Examples of the method of economic comparison of once-off investment? in a relatively expensive corrosion resistant alloy versus lower capital expenditure in a corrodible material with associated future operating costs are described in reference 12 This illustrates the method by which future operating expenditures can be actualised to present day values on the basis of the expected financial parameters including discount rate, inflation and taxation rate. It should be noted. however, that the results of this type of economic comparison are strongly dependent upon the input data and cannot be generalised

In comparing the cost of solid or clad pipes many factors, such as the diameter. the wall and cladding thickness and the strength of the materials. contribute. Larger diameters or heavy wall thicknesses produce a large increase in the cost of the solid alloy option whilst in the case of clad pipe these factors will only increase the carbon steel portion

As far as the mechanical strength is concerned, where the product has to be welded (such as in piping systems) the CRA has to be in the annealed condition when its strength is low. In such cases, the use of the CRA as a cladding rather than for the full wall thickness is highly beneficial since the backing steel may be much higher in strength and therefore less wall thickness is needed which reduces weight, handling costs and fabrication times For these reasons clad products are cost effective compared to solid alloy for such applications

By comparison, solid CRAs used for downhole tubulars are usually cold-worked to increase their strength to levels higher than can be achieved in the carbon steels normally used for clad pipe This should tend to favour the use of solid alloys for downhole tubular applications depending upon dimensional requirements and alloy type etc. A general cost comparison for downhole tubing (assuming the solid CRA to have a yield strength 1 4 times that of the carbon steel used for the backing steel in the clad casing) for sizes between 2" and 10" diameter, at a constant D/t ratio for the solid CRA of 20, and with the cladding thickness of 2mm is shown in Fig 2 The cost comparison depends on the ielative cost per kilogramme between the solid CRA and the clod material which is dependent upon the size, materials and manufacturing method used In the case show in Fig 2 material cost ratios between 1 and 3 are considered from which the relative cost of solid or clad pipes per metre has been derived For example, if the price of the solid alloy is the same as it is in clad form. the price ratio is I and solid pipes are seen to be always cheaper than clad pipes over the diameter range considered When the alloy considered is 3 times more expensive as solid than as clad, then the cost benefit of using clad pipe is very evident above 2".

When considering the use of clad pipes for surface applications (flowlines. pipelines, process piping), the use of clad becomes more economic, since tlie mechanical resistance of the *backing* carbon steel. is much higher than the solution annealed solid corrosion resistant alloy, as shown in Fig 3, where it appears clearly how clad pipe becomes cheaper than solid even for very low materials cost ratios and small sizes. Moreover, the larger tlie pipe diameter and the material cost, the higher are the economic henefits in using clad

3. MANUFACTURING OF CLAD PRODUCTS

Clad products may be manufactured by a wide variety of routes as described below appropriate to different dimensional requirements. A summary of the diinensional availability of clad products is given in the following Table (reproduced from table 5 reference 10).

3.1 Clad Plate

Clad plate can be produced by hot roll-bonding, explosive bonding and weld-overlaying More than 90% of world clad plate production (@55,000ton/year) is made by hot roll bonding The cladding and backing plates are separately prepared, cleaned and assembled with sometimes an electroplated layer of nickel or iron between the plates depending upon the specific manufacturer and the material combination It is normal to prepare a 'sandwich of two clad slabs with the clad surfaces together with a separating compound between them tu prevent the surfaces sticking The two slabs are welded together around ttic edges to prevent surface oxidation on the cladding

During rolling the increase in surface area of the slabs causes the surface oxides to break up which allows metal to metal contact to occur between the cladding and the backing metal so that a metallic hnnd forms in the solid state. After heat treatment the plates are separated, cleaned. cut to size and nnn-destructively examined

Explosive bonding uses the very short duration high energy impulse of an explosion to drive two slightly separated metal surfaces together, simultaneously cleaning away surface film? and creating a metallic bond Explosive bonding can be used for cladding most material combinations but is particularly preferred for cladding refractory metals such as Titanium and Zirconium directly onto steel Heat treatment is not always necessary after explosive cladding although strew relieving is advised for improving the bond ductility if refractory clad plates are to be subsequently fabricated

Various welding methods have been adapted to weld overlaying and have sometimes been used for the cladding finished pressure vessels as well as being used extensively for in-situ refurbishment of corroded vessels and other equipment Cladding by welding is only suitable for cladding materials which can be welded onto the backing steel, either directly. or possibly with an intermediate deposited layer to 'butter' the surface {such as pure. carbon-free, iron) Thus, most

Product	Wall Thickness (mm)	Width/Diameter (mm)	Max Length (m)
Roll Bonded plate	6 - 200mm Cladding 1 5mm - 40% of total wall thickness	1000 - 4450	16.5
Explosive bonded plate	Cladding 1 5 - 25mm min Base 3 times the cladding thickness no limit to max thickness of base	50 - 3500	5
with hot rolling		1000 - 4400	14
Overlay welded plate	base inetal > 5mm dad layer > 2.5mm	limited only by access of equipment	limited only by access of equipment
Longitudinally welded clad pipe	Total wall 6 - 60mm Liner < 1.6mm	100 - 1626	6 - 18
Lined pipe (thermal, shrink fit)	Total wall 5 - 30mm Liner 2 - 6mm	100 - 610	9 6 - 12 depending on size
Lined pipe (explosive mechanical joint)	Outer pipe > 5mm Liner 2 - 5mm (depending on diameter)	50 - 400	12
Seamless clad pipe (extruded and plug / mandrel mill)	Total wall 6 - 30mm Liner > 2mm	50-660	9 - 12 depending on size
Seamless clad pipe - explosive metallurgical joint	Outer pipe 2 - 20mm - Liner > 1.6mm	50 - 250	3 - 5
	4 - 25mm	20 - 240	2 - 16
Centricast pipe	Total wall 10-90mm Clad layer min 3mm	100 - 400	4-6
HIP clad pipe or fittings	Total wall > 5mm Clad layer min 2mm	25 - 1000	?
Weld overlay fittings	base metal > 5mm clad layer > 2 5mm	25 minimum	for small diameters limited by torch length e g. 1m for diameter 50mm No limit on large diameter.

iron and nickel based alloys can be readily deposited but refractory materials such as titanium cannot be used in the weld overlay form

3.2 Clad Pipe

Pipe ends of any of the products described may be supplied plain, bevelled, or threaded for couplings for downhole tubing.

The coupling design for clad pipe has to ensure that there is no risk of contact between the produced fluid and the backing steel. Suitable joint designs are available and tubing clad with alloy 625 and alsu with duplex stainless steel has becn used successfully in some corrosive oil and gas wells drilled to approximalely 3400m (10)

Longitudinally Welded Clad Pipe

Longitudinally welded pipe is made from clad plate The edges of the plate are machined for welding and the plate is formed into pipe in a UOE, press bend or rolling mill The longitudinal seam is usually welded from outside with submerged arc on the carbon steel portion, according to the various welding procedures available for carbon steel Tandem welding with two or more welding heads is usually employed ta speed up productivity. Welding procedures vary depending upon the wall thickness and pipe diameter Longitudinal welds are then back gouged to prepare a smooth surface for internal welding to complete the internal CRA layer

The filler material at the cladding surface has to be selected to have a corrosion resistance in the as-weld4 condition which is at least equivalent to the cladding alloy which is normally achieved by selecting an overalloyed filler material

Centricast Clad Pipe

First the well-refined molten steel is poured into a rotating metal mould with a flux. After casting the temperature of the outer steel is monitored. At a suitable temperature after solidification the molten CRA is introduced into the opposite end of the mould with a new flux. The selection of the flux, temperature of the outer shell when the molten CRA is poured in and the pouring temperature of the CRA are all important factors to achieve a sound metallurgical bond. By controlling these various parameters it is possible to achieve minimum mixing at the interface and maintain homogeneous wall thickness

Centrifugal casting is followed by heat treatment to solution anneal the cladding and normally quench and temper the outer pipe to achieve the required mechanical properties Finally, the pipc is machined along the full pipe length to remove the interdendritic porosity in the bore The outer surface is also lightly machined As a result of the machining step the finished pipe has excellent tolerance on diameter (±0 5mm) and wall thickness

Centricast clad pipe with alloy C276 cladding has already been used in a geothermal project for piping (13).

Seamless Clad Pipe

Seamless pipe can be produced by making a composite billet of CRA 'nested' inside the backing steel. This composite billet can be processed through standard pipe mills such as a plug mill, mandrel mill or extrusion press or forge It is the increase in surface area which breaks down the nxide layer on the CRA and carbon steel and allows a bond to form under the forces induced bv the plastic deformation within the mills It is important that the two metals in the billet are fastened together in some way before going into the mill to prevent them from rotating or separating. Different manufacturers use different methods to do this either by welding or using diffusion bonding (sometimes assisted by an activator on the interface surfaces).

There are fewer cladding alloys available in seamless tube because of the need to balance the hot workability of the cladding alloy and the backing steel As with longitudinally welded pipe there is a need to control the mechanical properties of the backing steel whilst optimising the corrosion resistance of the cladding This is normally achieved by a final solution annealing treatment followed by quenching and tempering Careful control of the backing steel composition is required to ensure that it meets specified requirements in the Q&T condition

The finished length of seamless pipe is dependent on the diameter since the weight of the incoming billet which can be handled is usually fixed. Thus. small diameter pipe may be obtained in lung lengths whilst larger diameter and heavier wall pipe may well be shorter than standard lengths depending upon manufacturers capacity. The maximum diameter available is 26"

HIP - Clad Pipe

Hot isostatic pressing (HIP) is a pressure assisted sintering/diffusion bonding process which has been used for the production of clad components and can be used for pipe production The corrosion resistant alloy may be in the form of a powder or a solid foil or sleeve depending on technical and economic considerations

The surfaces io be bonded are first prepared and cleaned and then brought into contact under pressure at elevated temperature. HIP is normally performed at a temperature above 1,100°C and at a pressure above 100 MPa for a few hours at full temperature and pressure, dependant on the type of alloy The total cycle time is about 8 - 12 hours By controlling the temperature and holding time. the diffusion zone depth can be controlled and limited. so there is no zone of dilution The temperature is actually dependent upon the type of alloy and is always less than the alloy melting temperature

When powder coating is used it is held in place by a can which is evacuated arid sealed prior to bring hipped The powder reaches 100% density during the HIPping process as well as atomic bonding at the surfaces. After HIPping tha can has tu be removed from the finished surface and the pipe may be heat treated to optimise the mechanical properties of thc backing steel

Almost any combination of materials can hc bonded and there are many HIP manufacturers world-wide Although the manufacturing process is labour intensive it is possible to HIP many parts simultaneously dependent upon the size and capacity of the equipment

Explosively Bonded Clad Pipe

A number of explosive fabricators world-wide are capable of manufacturing pipe with an internal explosively fully bonded clad layer The set-up for making this product varies with different manufacturers but takes one of two forms: expansion or implosion In both cases a small annular separation is maintained between the CRA and the carbon steel pipe surfaces to be joined so that there is an acceleration of the materials which therefore impact and bond together.

Mechanically Bonded Pipes (Lined)

Lining of pipe implies that there is no metallurgical bond between the liner and backing steel pipe except possibly in small areas at the pipe ends or along the pipe The methods of making lined pipe. described below, do not require the liner to bc heated into a range where any metallurgical changes occur Thus the mechanical properties of the backing steel can be optimised during the normal pipe production route and the solution annealed liner is inserted into this finished pipe. This opens up the possibility for a wider range of alloys to be available using these technologies with the unly requirement being that the liner should be weldahle

At its simplest, pipe can be lined by simply hydraulically expanding the liner into the outer pipe Alternatively, in the thermo-hydraulic gripping (THG) method the uuter pipe is first heated arid then the liner pipe is inserted with water cooling to prevent a temperature rise during insertion The water pressure is controlled so that the liner is plastically deformed until it touches the outer pipe and thcn the outer pipe is elastically expanded After that the pressure is removed so that both the outer pipe and the liner pipe shrink elastically The outer pipe is then cooled down to its initial diameter which is smaller than the diameter of the liner This generates the gripping stress on the liner and induces a compressive residual stress in the liner.

The final method available for manufacturing a lined pipe Is to use the explosive forming approach. The explosive force is sufficient to plastically deform the inner liner whilst the outer pipe is only elastically deformed. Thus the characteristic dimensions of the product are given by the outer pipe which retains its original dimensions. The process is a cold process so that it is highly suitable for a wide range of alloy and backing steel combinations, particularly high strength outer pipes, since there are no metallurgical effects to control One product incorporates explosively bonded strips along the pipc length tu prevent any risk of collapse in larger diameter pipes

The liner is welded to the backing steel at the pipe ends to facilitate girth welding. In some cases tho pipe is supplied with the pipe end completely overlay welded using an alloy appropriate to the liner material or with a special sleeve of solid CRA to facilitate bevelling or machining of couplings at the pipe end

3.3 Clad Fittings

Fittings can be produced from clad pipc by bot or cold forming processes. Bends and elbows are madc using high frequency induction bending, hot mandrel or hot-die bending. Tees are made by hot extruding or cold bulge forming In addition HIP methods and weld overlaying techniques are widely applied for producing clad fittings including tees, flanges, elbows, reducers and branches

In principle, any kind of fitting may be produced from clad pipe or plate Much care should be taken in maintaining strict tolerances, particularly on the ends, in order to facilitate welding into adjacent piping or other equipment It is also critical to control the heating and cooling cycles of the pari to avoid any metallurgical damage to the backing steel or cladding alloy

4. CONCLUSIONS

Given the highly corrosive environments which have to be handled in the geothermal industry and the cust benefits of reduced unscheduled downtime when CRAs are used, operating cost savings would be anticipated if more use was made of *CRAs*. By utilising clad products much less weight of expensive corrosion resistant alloy is needed and potential capital costs savings can be made Section 3 has described the range of production routes available for manufacturing clad products and shown that it is possible to engineer almost any item which might be required in clad form Successful application of clad products in other major industries over the last 40 years should encourage their increasing application in the geothermal industry

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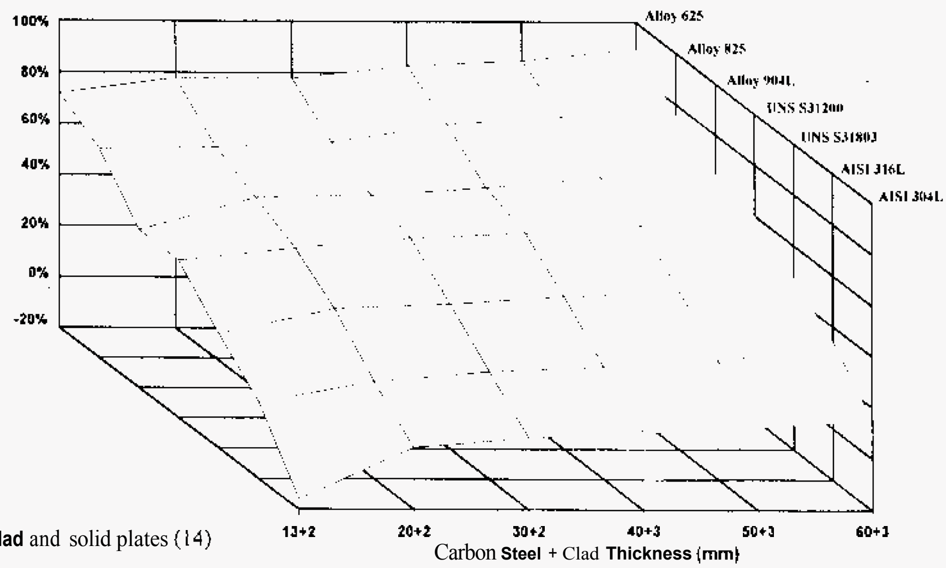

Fig 1 - Cost comparison between clad and solid plates (14)

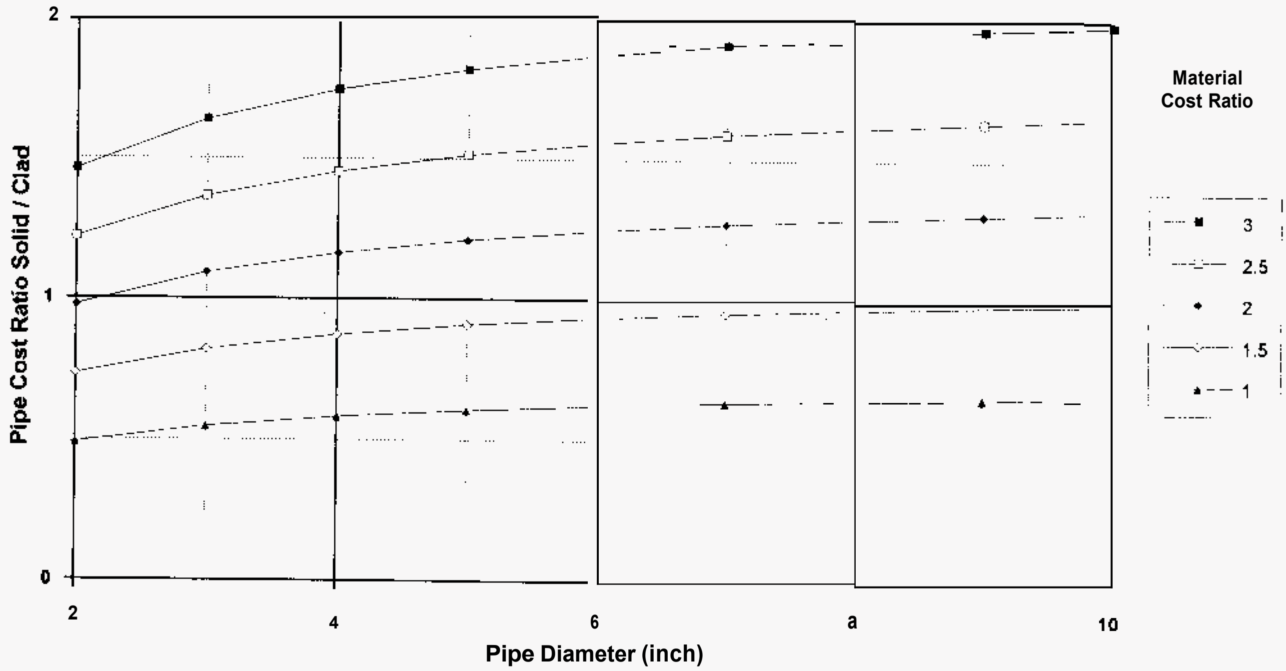

Fig. 2 - Cost Ratios of **Solid Corrosion** Resistant downhole casings **(costs per** meter of tube) vs pipe diameter as a function **of the** cost ratio **(per** kilogram) Strength of solid corrosion resistant alloy after cold **working was** considered 1.4 times the strength of **carbon** steel

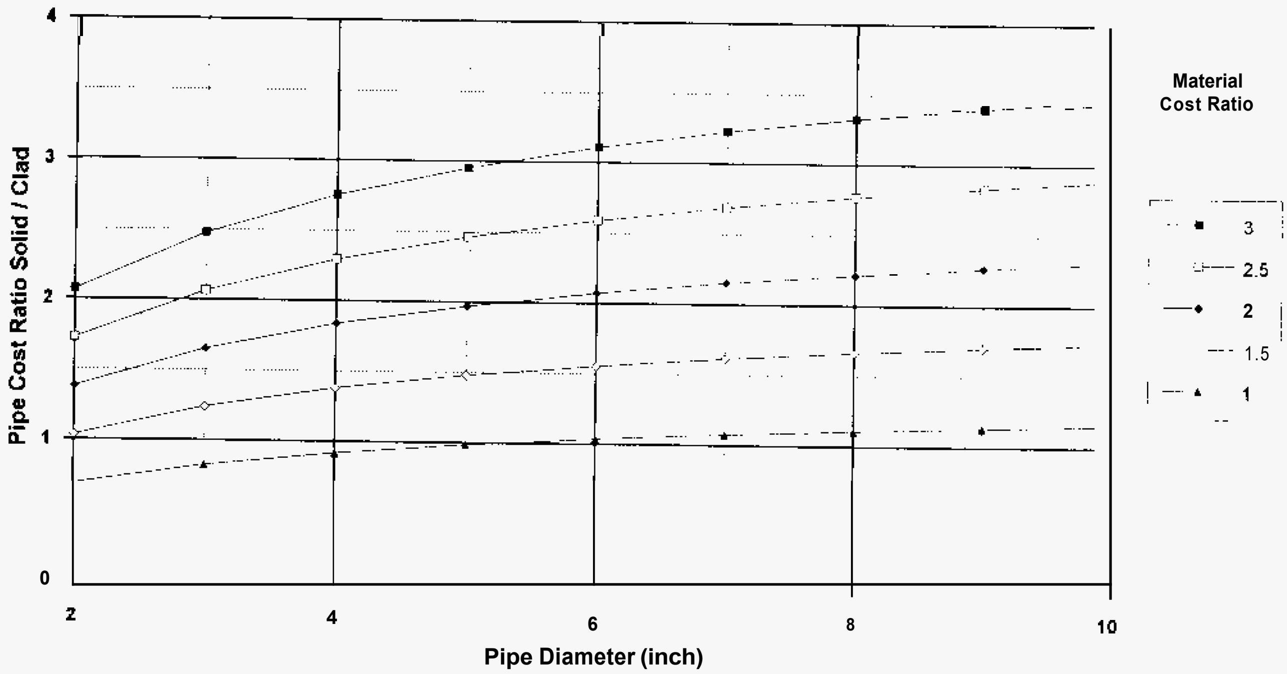

Fig 3 -Cost Ratios of Solid Corrosion Resistant **pipes** ***(costs* per meter** of tube) vs **pipe** diameter as **a** function ofthe cost ratio **{per kilogram). Strength of** solid corrosion resistant **in** solution annealed conditions allov was considered 0 7 times the strength of carbon steel