MATERIAL DEVELOPMENT TO MEET TODAY'S DEMANDS

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ABSTRACT

The construction of the early platforms in the North Sea often stretched materials technology to its limits and sometimes beyond them. There are many instances where major pumps or piping systems have had to be replaced either because the original materials were not sufficient for the duty or because the process fluids have become more corrosive during the life of the oilfield.

The paper reviews the considerable work that has been carried out in recent years specially directed at developing stainless steels capable of withstanding a number of the harsh corrosion environments met on offshore platforms. The latest stainless steels are able to withstand all the standard seawater duties without suffering from localised pitting or crevice corrosion. Their resistance to hydrogen sulphide stress corrosion means they can cope with the most sour process fluids at present met in the North Sea.

Particular case studies discussed include;

1). Using duplex stainless steels instead of the standard austenitic stainless stees to eliminate fatigue failure of pump impellers.

2). The use of these newer materials on seawater or firewater systems in places where galvanised mild steel has corroded or cupro-nickel has suffered from erosion corrosion or hydrogen sulphide attack.

3). Replacing existing materials on new or replacement flow lines, especially for wells that are becoming increasingly corrosive in terms of the actual process fluid or produced water.

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INTRODUCTION

Most experienced production/maintenance people can recount examples of major failures which were costly either because of the major impact of one failure or because repetitive failures were experienced. To the direct cost of rectifying the fault, we nearly always have to add in the cost of lost production.

This year is in fact the 75th anniversary of the discovery of stainless steels by Harry Brearley in Sheffield. The demands of the oil industry have been so strong that the corrosion performance of stainless steels has progressed more in the last 10 years than the previous 65.

The traditional stainless steels used by industry have been the martensitic 13% Cr and austenitic 18% Cr, 10% Ni stainless steels. These have a minor part to play on offshore applications, but on their own they fail completely under sea water, produced water or sour environments, especially when the corrosion environment is complex.

The development of stainless steels for offshore applications in the last few years can be split into 4 types which fall into 2 generic groups (Table 1). The development timetable has been as follows:

AUSTENITIC STAINLESS STEELS	DUPLEX STAINLESS STEELS
	22% chromium
	25% chromium high alloy
high molybdenum	
	25% chromium super duplex

CHEMICAL COMPOSITION

When developing a new stainless steel the metallurgist is faced with a number of objectives. As normal, some of these objectives are complementary and some contradictory. The final level of alloying elements therefore has to achieve the right balance so that the following performance is achieved.

- maximise corrosion performance.
- achieve mechanical properties appropriate to process environment.
- maximise workability for - cast material
  - wrought material
  - fabrication
- minimise cost

CORROSION PERFORMANCE

In the environments encountered on the oil platforms, the corrosion mechanism which limits the application of a stainless steel is localised corrosion, where the passive film present on the surface of the stainless steel breaks down and the parent metal is attacked., ie pitting and crevice corrosion.

Frequently the performance of stainless steels is tested using potentiostatic polarisation techniques. The results of these tests are plotted as an anodic polarisation curve Fig 1. The corrosion performance of the material can be improved if the passive potential region can be extended at both ends and if the passive current density is reduced

A summary of the effect of certain alloying elements on the anodic polarisation curve of stainless steels is shown in Fig 1 [1]. The elements that have the most beneficial effect on the resistance to localised corrosion of a stainless steel are found to be chromium, molybdenum, nitrogen and tungsten.

The addition of chromium (over 13 wt%) to iron results in the formation of a protective chromium oxide film which isolates the steel from the environment. In chloride solutions the formation of the protective film expands the passive potential range by increasing the pitting potential and reducing the passive current density (Fig 2). For the stainless steels under discussion, the chromium level varies between 20-26%.

For a given chromium content, molybdenum has a strong beneficial effect on a steel's passitivity, primarily by increasing the pitting potential and lowering i_{max} (Fig 2). The mechanism by which molybdenum exerts its influence is not fully understood [2,3] but may be associated with its inhibition of the active dissolution rate in incipient pits [4].

From a practical point of view it is necessary to have a high chromium and molybdenum content in the stainless steel to prevent crevice corrosion in warm sea water. Molybdenum however increases the rate at which intermetallic phases (principally sigma) are formed in stainless steels and these reduce the mechanical and corrosion performance of the stainless steel. Thus the later stainless steels have 3-4% Mo in the super duplex stainless steels and up to 6% Mo in the high moly austenitic stainless steels.

Nitrogen additions improve the localised corrosion resistance of the stainless steels by increasing the pitting potential. [5] The beneficial effect of nitrogen appears to be enhanced by the presence of molybdenum. [6] More recent work suggests the beneficial effect on nitrogen on pitting corrosion is associated with the blocking effect of nitrogen on anodic dissolution in the local chemistry of a pit [8]. In duplex stainless steels, nitrogen may also improve corrosion resistance by reducing partitioning of the chromium to the ferrite phase [9]. Nitrogen has however only a limited solubility and so there are practical limits to which the nitrogen level can be increased without incurring the risk of gassing in castings or ingots.

Tungsten (like molybdenum) has been shown to extend the passive potential range and increase pitting potential when added to duplex stainless steels [10]. Its effect may enhance corrosion properties be being adsorbed into the passive film as WO_3 [11]. WO_3 then interacts with the oxides, resulting in enhanced stability and improved bonding of the film to the base metal.

The beneficial effects of the various alloying elements can be assessed and combined to give an indication of a stainless steel's corrosion resistance. Such a compositionally derived empirical relationship for pitting resistance of stainless steels is known as the steels Pitting Resistance Equivalent (PRE_N).

$$PRE_N = \%(Cr) + 3.3\%(Mo) + 16\%(N)$$ [12]

Figure 2 shows how the relationship between the basic PRE_N value of a stainless steel and its pitting temperature in seawater can be represented as a straight line. It can also be concluded from this Figure that the inclusion of tungsten in the formula as follows

$$PRE_N = \%(Cr) + 3.3\%(Mo + W) + 16\%(N)$$

above decreases the amount of scatter and improves the correlation. Further work is required to refine the PRE_N formula so that the beneficial/detrimental effects of all alloying elements and the microstructural factors associated with the breakdown of passivity are considered.

From the Figures 2 and 3 it can be seen that the 22% Cr duplex stainless steels have superior pitting and crevice corrosion performance to the 316 austenitic stainless steels. The increase is not however sufficient to allow it to be used on seawater duties. The main advantage of the 22% Cr duplex stainless steels over the standard austenitic stainless steels is mainly that they give execellent resistance to chloride stress corrosion cracking, whilst giving some resistance to sulphide stress corrosion cracking in low H_2S partial pressure environments..

It is generally considered that PRE_N values of greater than 35 are necessary to determine whether an alloy will display good pitting performance in low temperature seawater or deaerated seawater. This value can be achieved by using the standard 25% Cr duplex stainless steels (Table 1) and these alloys have now seen extensive service on these types of duties.

A PRE_N value of greater than 40 is necessary to guarantee the localised corrosion resistance of a stainless steel in oxygenated sea water. Only the super duplex and high molybdenum austenitic stainless steels satisfy this criterion (Table 1).

MECHANICAL PROPERTIES

Table 2 shows the relative mechanical properties of the later generation stainless steels.

The 22% Cr duplex stainless steels show a considerable increase in proof and ultimate tensile strengths compared to the standard austenitic stainless steels.

They are therefore used on many applications where the corrosion resistance of a standard austenitic is sufficient, but weight and economic gains can be made because of the high strength of the duplex stainless steels.

The 25% Cr duplex stainless steels show no mechanical advantage over the lower alloyed duplex steels and their advantages, as detailed above, are in their increased corrosion performance.

The high molybdenum austenitic stainless steels show significant strength increases over the standard austenitic stainless steels, but they possess considerably lower mechanical properties than any of the duplex stainless steels.

The 25% Cr super duplex stainless steels are at the top of the range of mechanical properties with excellent strength properties coupled to good toughness levels. Their high strength leads to weight reductions on high pressure pumps and pipework over alternative materials, even including lower alloyed duplex stainless steels and the high moly austenitic stainless steels.

WORKABILITY - CAST MATERIAL

In general the foundry properties of the duplex stainless steels are good. Risering and gating practices are similar to those employed in the production of the austenitic type alloys. Hot tearing is not a problem. However difficulties can arise resulting from cold cracking in the mould, if careful attention to producing the optimum phase balance is not made.

In contrast the high moly austenitic steels suffer from solidification cracking, (hot cracking) and can suffer from cold cracking in the mould, a phenomenon which is sometimes referred to as chicken wire cracking. It is thus fairly difficult to obtain high quality complex castings in the high molybdenum austenitic stainless steels.

WORKABILITY -WROUGHT MATERIAL

The hot working procedures for the high moly austenitic and the duplex stainless steels are generally in line with the austenitic stainless steels, only they have smaller hot working bands and this calls for close control of the manufacturing procedures. Though the duplex stainless steels have much higher design stresses than the high moly austenitic at operating temperatures, the loads experienced during hot working are in fact much lower.

A natural conclusion from some of the experimental work described earlier is that the excellent corrosion performance of these materials can be considerably reduced by incorrect casting, heat treatment and fabrication procedures. At all stages, close manufacturing procedures must be followed and it is imperative that only suppliers/fabricators fully conversant with these materials should be used.

WORKABILITY - FABRICATION

Systems have to be fabricated and thus the performance of the welds is paramount.

It is necessary to consider the combined influence of the PRE_N value and the microstructure to determine the localised corrosion performance of stainless steel weldments. To demonstrate this fact, a series of weldments have been produced in conventional duplex, super duplex and 6Mo austenitic stainless steels.

Accelerated localised corrosion assessments have been carried out on all the weldments in 10%$FeCl_3$ solution in accordance with ASTM G48. The results of these investigations are summarised in Table 3. From the results obtained, it can be deduced that the weldments in both the as-welded and solution annealed conditions can be ranked in terms of their critical pitting and critical crevice temperature in the ferric chloride solution as follows:

super duplex > high moly austenitic > 22% Cr duplex.

The solution heat treated weldments generally give critical pitting and critical crevice temperatures which are similar to those observed for the parent materials.

Welding in the fabrication yard has normally to be carried out without the luxury of post weld heat treatment. The performance of the as-welded components is therefore important. It can be seen that there is a small reduction in the corrosion performance of the as-welded materials. Even so the performance of the super duplex stainless steels was excellent with critical crevicing temperatures of 50-60°C achievable. In contrast some of the as-welded plates on the 6Mo weldments displayed very severe pitting in the weld metal on the unmachined test specimens when tested at 40°C. whilst crevice corrosion of the HAZ can occur at 35°C.

The reduction in the corrosion performance of the weld metal and HAZ for the high Mo austenitic steels is attributed to the precipitation of secondary phases. These phases locally denude the main matrix of corrosion resistant elements in the surrounding areas. This in turn lowers the pitting and crevice corrosion resistance of the weld metal and parent metal matrix within the HAZ region.

The high molybdenum austenitic stainless steels have been found to be very sensitive to welding parameters. Additional tests were therefore carried out on the super duplex stainless steels in which the heat input levels were purposely varied to determine the permissible variation from the optimum welding parameter. Even with wide variations in heat input from 0.97-3.12 kj/mm, only isolated pitting is observed for the super duplexes in the unmachined as-welded specimens when tested at 45°C and the crevice corrosion is only just discernable on the machined specimens at 45°C.

Thus even when certain secondary phases are present in the super duplex weldments as a result of incorrect welding practices, the localised corrosion performance of these weldments is still better than that observed for the 6Mo austenitic stainless steel weldments. Thus even though the P12 filler utilised on the 6Mo weldments had a high PRE_N value of 50.0, the tendency to form high molybdenum containing phases and microsegregation in the weld metal markedly reduce the corrosion performance of the 6Mo weldments.

APPLICATIONS

The various stainless steels have now been used in a number of application areas on offshore platforms. The following gives three application areas where the mechanical properties, the corrosion properties and the combination of mechanical and corrosion properties have been used to solve actual operational problems.

IMPROVED MECHANICAL PERFORMANCE-HIGH PRESSURE PUMPS

Even on high pressure pumps the vast proportion of the pump body and rotating elements are designed with stresses well within the allowable design limits, as other design criteria are relevant, particularly stiffness. Impellers do however have two failure modes resulting mainly from a combination of poor design, selection of material or incorrect operating practice.

- Failure in the hub area, due mainly to rotational stresses or incorrect transmittal of the driving torque.

- Fatigue failure of the shroud of the impeller between two vanes.

If a 25% Cr duplex/super duplex stainless steel is used instead of an austenitic stainless steel, then the operating design stress/allowable design stress ratio can be reduced considerably, to well within acceptable levels

In fact, foundry techniques have also been developed to complement the introduction of these newer materials, with the introduction of ceramic core moulding techniques and improved moulding and feeder practices. Experienced pump repair companies can sometimes take advantage of these improvements by redesigning and reducing shroud/vane thicknesses, improving vane profile and therefore the pump performance can be improved or altered to match the actual operating conditions being found on the plant.

IMPROVED CORROSION - SEA WATER AND FIRE WATER SYSTEMS

The handling of seawater on oil platforms has been a problem, right from the very start. The material selection has progressed from galvanised carbon steel, concrete lined steel through to cupro-nickel. For each of the materials selected there has been a list of operating problems. Table 4 gives a short summary of some of the major problems that have been experienced.

A number of studies have been carried out to compare the highly alloyed stainless steels with cupro-nickel. The results of one such study [18] of a deluge system concluded the following.

- Due to velocity limitations with cupro-nickel, the system is unable to utilise the available inlet pressure. As a result it would be necessary to install an orifice plate to create a 4.72 bar pressure drop at the deluge valve set.
- The super duplex stainless steel system has smaller pipes throughout and as a consequence a smaller deluge value set would be required.
- As a result of the smaller bore stainless steel system, the dry weight is reduced by 15% compared to cupro-nickel and the wet weight by 33%.
- The increased strength of stainless steel enables 38% few pipe supports to be used and eliminates the need for the comprehensive insulation kits.

Typical costs of a stainless steel pipe and fittings package relative to those in a cupro-nickel deluge system are presented in Table 5. The overall cost of the system components are greatly reduced using super duplex stainless steel in place of 90/10 cupro-nickel. Support and prefabrication costs are also much lower for the super duplex stainless steel. Other savings would also arise from the use of smaller deluge valve sets and skids. The super duplex stainless steel is also easier to handle, whereas the cupro-nickel is prone to damage.

On systems such as deluge systems, the comparatively high strength of the stainless steels is not utilised. For instance, the design pipe wall thickness required for a 4" pipe operating at 20 bar is only 0.5 mm. Even on larger diameter ring main and utility system pipework, the full design stress of the stainless steels is not utilised. Despite this, there are still significant weight and cost savings to be gained by using high alloy stainless steels instead of cupro-nickel. (Table 6)

IMPROVED MECHANICAL AND CORROSION PERFORMANCE - PROCESS SYSTEMS

There is an increasing tendency, particularly in Norway, to specify the super duplex and high moly austenitic stainless steels in preference to the standard 22% Cr duplex stainless steels. The rationale supporting this departure from past practice has little to do with chloride and sulphide stress corrosion cracking and is concerned principally with localised corrosion performance. The practice in the UK has varied from regularly replacing carbon steel pipework to installing expensive nickel alloy pipe systems. As flow lines tend to operate at fairly high fluid velocities, it has however been found that inhibitors and the use of coatings, particularly on carbon steel, has often not proved successful.

Process fluids in the latest generation of oil and gas fields have higher water cuts than previously encountered. The aqueous phase is frequently at elevated tem peratures and often contains high proportions of chlorides and H_2S. The 22% Cr duplex stainless steels do not give adequate resistance to pitting and crevice corrosion, particularly in weldments.

Whilst the high molybdenum austenitic stainless steels have the necessary corrosion resistance, there is a need on a high pressure process system for high strength materials. Nearly all of the process system can be designed lighter, often upto 30%, in a super duplex material than in a high moly austenitic, Significant weight and cost savings and therefore be achieved.

Table 7 shows the results of one analysis carried out to look at the total installed costs of pipework systems. Whilst the material costs of stainless steel pipework may be considerably higher than for carbon steel, it has been found that the installed cost is only of an order of twice the cost. This analysis was also carried out using fabrication costs within a module yard. If this analysis was repeated fully with the total costs of offshore fabrication work included, then it would be found there is only a small additional cost of using the optimum stainless steel pipework material. The vagaries of most oil company's accounting analysis systems probably makes it easier for the maintenance man to install the correct material during a refurbishment exercise, rather than installing the correct material initially.

CONCLUSIONS

1. The use of a Pitting Resistance Equivalence (PRE_N) formula incorporating tungsten, provides a simple method of predicting the localised corrosion performance of stainless steels. However, microstructural factors that affect corrosion performance must also be considered.

2.The critical pitting and critical crevice resistance in ferric chloride of the high alloy stainless steel weldments tested can be ranked as follows:

super duplex > high Mo austenitic stainless steels > 22% Cr duplex.

3. The use of super duplex stainless steels affords considerable scope for cost reduction when specified for offshore pipework systems. In respect of fire water systems, displacement of cupro-nickel alloys leads to significant direct and indirect cost savings through reductions in material usage (dry weight) and impressive associated savings in wet weight. In respect of process pipework, the savings that accrue from the specification of super duplex steels in preference to the high Mo austenitic grades cannot be overstated.

4. When the full costs of installing pipework systems offshore, either new systems or as replacements, are taken into account, then the cost difference between low corrosion performance materials (carbon steel) and the correctly specified high alloy stainless steel (generally the super duplex grade) is small. Installing the correct material once, rather than continuing a policy of replacing cheap pipework systems, is now an economic solution.

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TABLE 1

NOMINAL COMPOSITIONS OF HIGH ALLOYED STAINLESS STEELS

CLASS	MATERIAL	Cr	Ni	Mo	Cu	W	N_2	PRE_N
DUPLEX STAINLESS STEELS								
22% Cr	SAF 2205	22	5	2.5			0.13	30.5
25% Cr	ZERON 25	25	6.5	2.5	0.3		0.18	35
25% Cr super	ZERON 100	25	7	3.5	0.7	0.7	0.22	40 41.8 INCL TUNGSTEN
HIGH MOLY AUSTENITIC								
6% MOLY	254SMO	20	18	6	0.5		0.2	42.1

TABLE 2

MECHANICAL PROPERTIES OF HIGH ALLOYED STAINLESS STEELS

CLASS	MATERIAL	0.2% PROOF STRESS MPa	TENSILE STRENGTH MPa
DUPLEX STAINLESS STEELS			
22% Cr	SAF2205	450	620
25% Cr	ZERON 25	480	650
25% Cr super	ZERON 100	550	750
HIGH MOLY AUSTENITIC			
6% MOLY	254SMO	300	650

TABLE 3

SUMMARY OF FERRIC CHLORIDE CORROSION TEST RESULTS OBTAINED FROM PRODUCTION WELDING TRIALS CONDUCTED ON ZERON 100, 6Mo AUSTENITICS AND SAF 2205 STAINLESS STEELS

MATERIAL	PRE_N (BASE METAL)	PRE_N (FILLER METAL)	CONDITION OF MATERIAL	HEAT INPUT (kJ/mm)	CPT (°C)	CCT (°C)
ZERON 100 BASE METAL	41.7 (43.7)	-	MILL FINISHED PLATE	-	65-75	60-65
ZERON 100 GTAW WITH ZERON 100 SW	41.2 (43.1)	40.1 (42.0)	AS WELDED PLATE	0.97-3.12	45-55*,**	45-50*,**
	41.3 (43.2)	41.6 (44.0)	AS WELDED PLATE	1.95	55-65**(1)	50-60**
ZERON 100 GTAW WITH ZERON 100 MMCW	41.5 (43.6)	42.5 (44.3)	SOLUTION ANNEALED	0.9-2.1	65-75	55-65
6 Mo AUSTENITICS BASE METAL	43.3/45.4	-	MILL FINISHED PLATE	-	55-65	45-55
6 Mo AUSTENITICS GTAW WITH P12 FILLER	43.3/45.4	49.0/49.8	AS WELDED PLATE	0.9-1.1	35-45*(1)	35-45*,**
6 Mo AUSTENITICS GTAW WITH P12 FILLER	43.3/45.4	49.8	SOLUTION ANNEALED	0.9-1.1	50-55	NOT ASSESSED
2205 BASE METAL	33.4/34.2	-	MILL FINISHED PLATE	-	25-35	15-25
2205 GTAW WITH 22.8.3 FILLER	33.4/34.2	34.3	SOLUTION ANNEALED	2.0	20-35	NOT ASSESSED

N O T E:

PRE_N FIGURES IN BRACKETS ARE ADJUSTED TO INCLUDE TUNGSTEN

* Localised corrosion in the weld metal

** Localised corrosion in the HAZ

(1) Optimum heat input

TABLE 4

ADVANTAGES AND DISADVANTAGES OF MATERIALS IN RING MAIN, DELUGE AND SPRINKLER SYSTEMS

MATERIAL	RING MAIN	DELUGE SYSTEMS	SPRINKLER
CARBON STEEL CEMENT LINED	UNACCEPTABLE SEVERE WT. PENALTIES HIGH INSTALLATION COSTS NOT NOW NORMALLY SPECIFIED	UNACCEPTABLE	UNACCEPTABLE
CARBON STEEL LINED/GALVANISED		CORROSION DUE TO EVAPORATION/ CONCENTRATION IN SEAWATER DROPLETS REMAINING AFTER TESTING. CORROSION PRODUCTS LEADS TO TO NOZZLE BLOCKAGE.	RISK OF NOZZLE FAILURE. EXAMPLES OF FAILURE HAVE HAVE BEEN REPORTED
CUPRO-NICKEL	CORROSION PERFORMANCE GENERALLY GOOD. OCCASIONAL DAMAGE BEHIND WELDS AND AT BENDS DUE TO EDDYING. VELOCITY LIMITATIONS/ LOW STRENGTH REQUIRES LARGER PIPE SECTIONS.	CORROSION PERFORMANCE O.K. DRY SYSTEMS HAVE HIGH POTENTIAL FOR HEAT DAMAGE, IN THE EARLY STAGES OF A HYDROCARBON FIRE. VELOCITY LIMITATIONS REQUIRES LARGER PIPE SIZES.	GENERALLY SATISFACTORY
STANDARD STAINLESS (316)	UNACCEPTABLE	HIGH SALT CONCENTRATIONS COMBINED WITH EVAPORATION IN SMALL POOL AND DROPLETS LEADS TO SEVERE PITTING AND PERFORATION AND RISK OF NOZZLE BLOCKAGE BY CORROSION PRODUCTS	RISK OF PITTING AND PERFORATION.
SUPER DUPLEX SUPER AUSTENITIC	OPTIMUM SOLUTION	IDEAL SOLUTION	IDEAL SOLUTION

N O T E PERHAPS SURPRISINGLY MORE PROBLEMS AND FAILURES ARE REPORTED IN NOTIONALLY DRY DELUGE SYSTEMS THAN IN RING MAIN OR SPRINKLER SYSTEMS ILLUSTRATING THE UNEXPECTEDLY HARSH ENVIRONMENT THAT EXISTS.

TABLE 5

CASE STUDY OF A TYPICAL 40 NOZZLE DELUGE SYSTEM

5a ALTERNATIVE DESIGNS

PIPE DIA. (INCHES)	LENGTHS OF PIPE REQUIRED (METRES)	
	90/10 CUPRO-NICKEL	SUPER DUPLEX
1	36.65	52.4
1.5	23.85	33.5
2	25.4	5.9
3	11.5	28.5
4	22.85	25.0
6	25.03	-
VALVE SET (MM)	150	100
NO. OF SUPPORTS	55	34
INLET PRESS REQD. (BAR)	5.28	10
FLOW (LITRES/MIN)	4368	4880
PIPE VOLUME (LITRES)	809	472
DRY WT. (KGS)	634	542
WET WT. (KGS)	1442	960

5b COSTS

	90/10 CUPRO-NICKEL (£)	ZERON 100 (£)	CHANGE (£)
PIPING MATERIAL	6500	6400	-2
SUPPORTS	1100	680	-38
PREFAB LABOUR	7000	4000	-43
TOTAL	14600	11080	-24

5c WEIGHTS

	90/10 CUPRO-NICKEL	SUPER DUPLEX
DRY WT. (TONNES)	28.5	24.3
WET WT. (TONNES)	46.3	36.8

Table 6
Case Study of a Typical Firewater Ring Main
6a Lengths of Materials Reqired (metres)

Pipe Dia. (inches)	18	12	8	6	4	3	2
Cupro-Nickel (3.5m/sec)	170	-	5	30	40	-	-
Zeron 100 (7m/sec)		170	-	5	30	40	-
Zeron 100 (12m/sec)			170	-	5	30	40

6b Weights

	90/10 Cu-Ni 3.5m/sec	Zeron 100 (7m/sec)
Dry Wt. (tonnes)	17.4	6.7
Wet Wt. (tonnes	46	19
Pipe Supports (No.)	123	82

6c Costs

	90/10 Cu-Ni (£)	Super Duplex (£)	Change (%)
Piping Material	96000	60000	-38
Supports	3700	1650	-55
Prefab Labour	32010	9500	-70
Total	131700	71150	-46

TABLE 7

COMPARISON OF TOTAL INSTALLED COST FOR PIPING

MATERIAL	COST RATIO
CARBON STEEL	1,00
TYPE 316L	1,56
20Cr-25Ni-4,5Mo (904 TYPE)	1,90
22Cr DUPLEX	2,07
20Cr-25Ni-6Mo (254 SMO TYPE)	2,76
ZERON 100 SUPER DUPLEX	2,10
CARBON STEEL RUBBER LINED	2,83

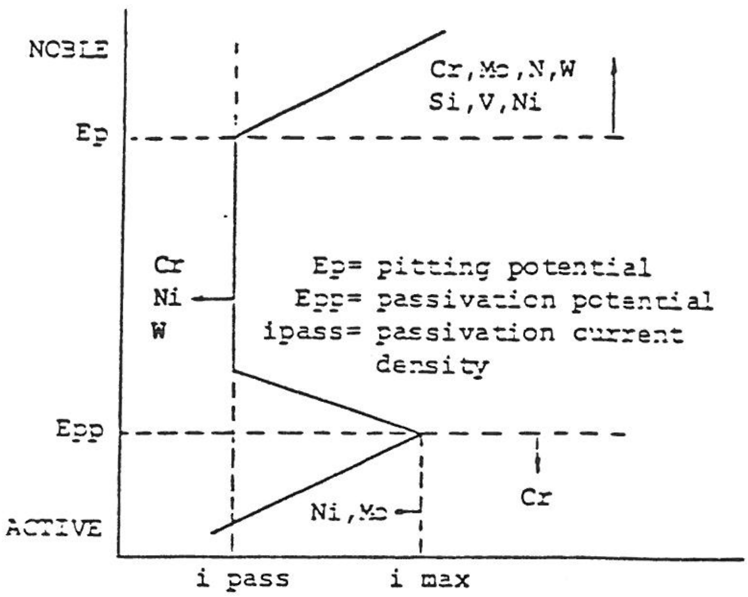

Figure 1 Schematic representation of the effects of certain alloying elements on the polarisation curve of stainless steels(1).

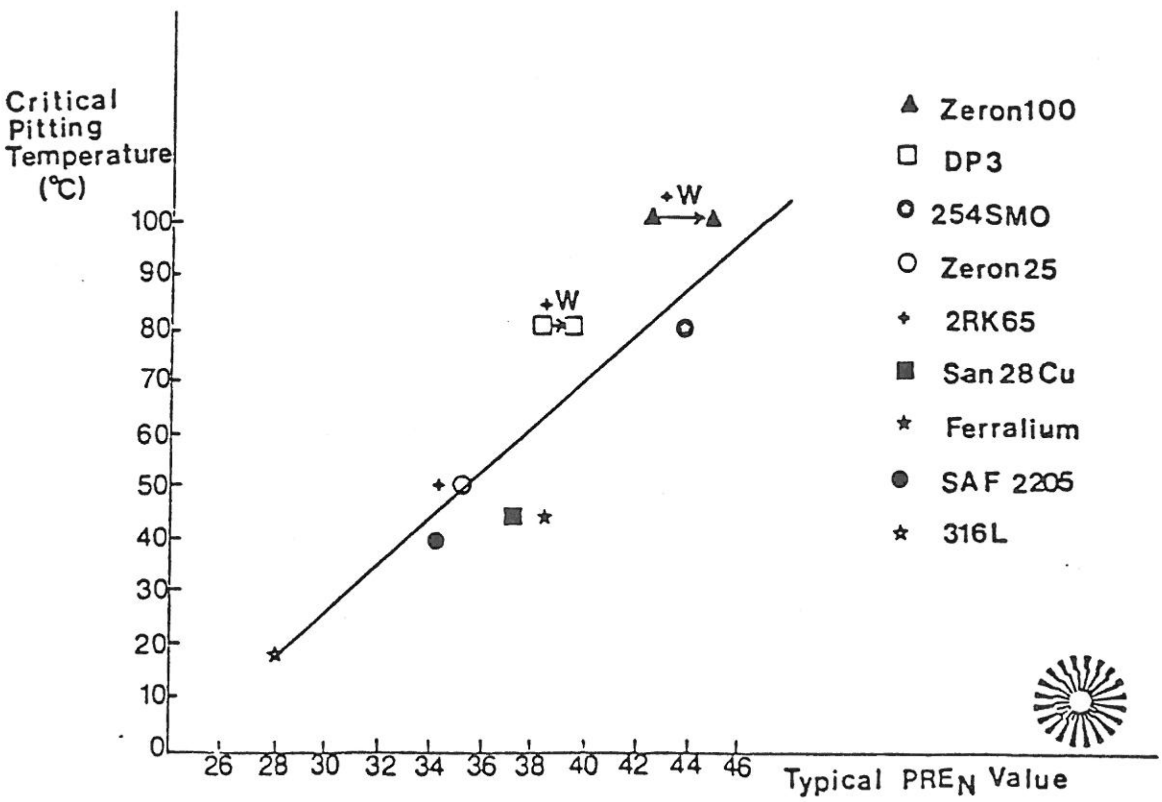

Figure 2 PRE_N (%Cr + 33%Mo + 16%N) and tungsten adjusted PRE_N (%Cr + 3.3(%Mo + %W) + 16%N) versus critical pitting temperature for a selection of stainless steels.

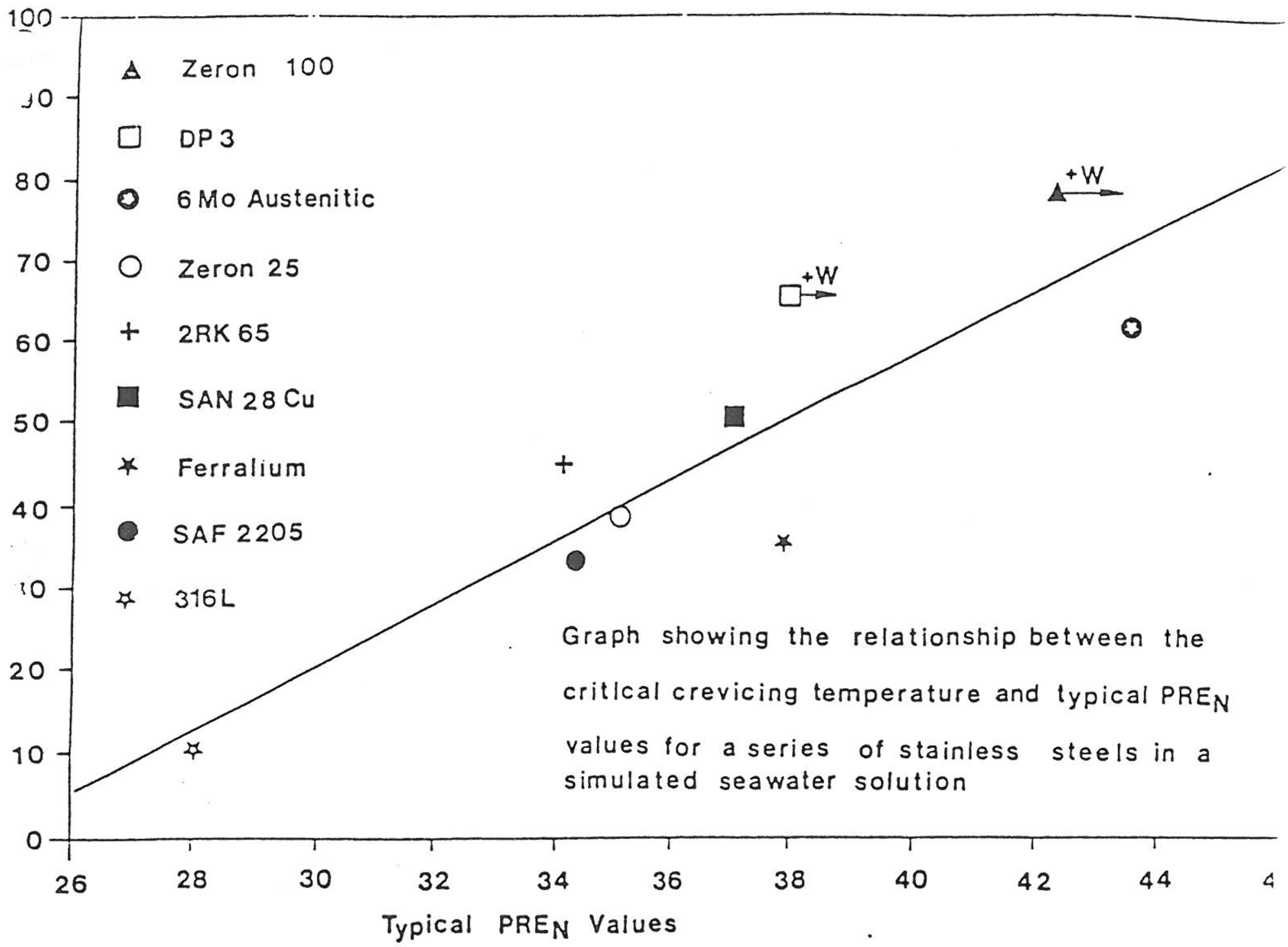
Zeron 100
DP 3
6 Mo Austenitic
Zeron 25
2RK 65
SAN 28 Cu
Ferralium
SAF 2205
316L
+W
+W
Graph showing the relationship between the critical crevicing temperature and typical PREN values for a series of stainless steels in a simulated seawater solution
100
80
70
60
50
40
20
10
0
26
28
30
32
34
36
38
40
42
44
Typical PREN Values

Fig.3