A NEW ALLOY FOR PHOSPHORIC ACID SLURRIES

by

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INTRODUCTION

The wet process for phosphoric acid production is especially arduous on pumping equipment because of the extremely corrosive and erosive nature of the slurries which have to be handled. Critical pump services such as flash cooler, filter feed, and gypsum removal are especially severe because of the high solids concentrations. The short wear life of some pumps in these duties (as low as a few thousand hours) can make these pumps very expensive to maintain. Typical materials used in phosphoric acid slurry pumps to date have been stainless steels and elastomers. Elastomer materials have been more successful for pump liner applications than for impellers because of the possibility of tramp or oversized material causing cuts and/or tears in the impeller. Where stainless steels have been used, it is not uncommon for local erosion to cause premature failure of the part. Stainless steels whilst offering good corrosion resistance are simply not hard enough to provide good wear resistance.

Over the last few years Warman International has been developing a new white iron alloy for slurry pump applications which would replace stainless steels in high wear applications. The new Ultrachrome® A51 alloy is considerably harder than stainless steels while still providing adequate corrosion resistance to enable a dramatic improvement in overall life of the pump. Trials of the new A51 alloy in Central Florida have shown significant cost benefits over previous materials. This paper outlines the background to the material's development and details its properties, performance and field trial results to date.

SLURRY PUMP DESIGN & MATERIALS

There are two typical slurry pump designs which can be differentiated by the style of casing. The unlined or single case slurry pump takes the full stress due to external pipe loading and internal pressurisation of the pump. This design may render the use of brittle materials impractical. In addition, the unlined pump is not easily fitted with an elastomer lining because they have to be glued-in and liner replacement is difficult. Optimum physical properties of the elastomer may also need to be compromised in choosing a glued-in liner system.

The second style of slurry pump is the lined pump. This design is illustrated in Figure 1. Its main advantage is that the ductile iron outer case takes most of the flange loading and stresses due to internal pressure. Optimum material selection for phosphoric acid duties is dependent on the specific conditions. Acid concentration (particularly impurities) as well as solids concentration, particle sizing and temperature all play important parts. Use of the lined pump design means that either elastomer or brittle white iron or stainless steel materials can be used interchangeably. Warman pioneered the concept of interchangeable lining materials over 50 years ago and is the largest producer of this type of pump in the world today.

Elastomers have been used widely for pump liners in phosphoric acid plants as they exhibit excellent chemical resistance and good erosion resistance to fine particle slurries. Because of the high acid concentration and high temperatures that are present in these slurries, the synthetic rubbers, Butyl and Neoprene, have shown the best combination of properties. In straight phosphoric/sulphuric acid applications Butyl has better chemical resistance than Neoprene. This advantage may be offset somewhat by the better wear resistance of Neoprene (see Figure 2 for comparison). Several Warman installations in Sweden, the U.S.A. and Australia use synthetic Butyl or Neoprene elastomers in applications with temperatures up to 100°C.

In many phosphoric acid plants the large amounts of gypsum in circulation, together with fluctuating pH levels often leads to significant amounts of scaling and this is an important factor in deciding between the use of elastomers and alloys. Elastomers may be damaged (cut) by the impact of large particles. Any cut in the elastomer covering which penetrates to the reinforcing will inevitably lead to early failure due to subsequent corrosion of the reinforcing inside. While impellers can be manufactured in either elastomer or alloys, due to the potential problems of scaling, it is desirable to install a metal impeller to prevent damage from this scale or other "tramp" material. Liners are generally not affected to the same extent by tramp material because of the much lower impact velocities and impingement angles. The optimum configuration is generally a combination of elastomer liners and metal impeller and throatbush.

Many different stainless steels have been used in phosphoric acid services including 316, Alloy20 and the duplex stainless steels CD4MCu and Ferralium®. The 316 series stainless and Alloy 20, while providing good corrosion resistance, are not as hard as the duplex stainless steels and do not wear as well. Even the duplex stainless steels however were considered to have inadequate wear life.

Typical properties and compositions for a range of stainless steels and elastomers used in phosphoric acid applications are shown in Table1.

A NEW ALLOY

After discussions with various customers in Florida in 1989, Warman committed to the development of a new white iron which would have the same corrosion resistance as the duplex stainless steels but which would offer significantly better erosion resistance. The route for this development was to start with a high chromium white iron and to look at opportunities for improving corrosion resistance while still maintaining the basically carbidic microstructure which gives good hardness and wear resistance.

Erosion/Corrosion Mechanisms

The mechanism of material removal in acid slurries is through a combination of erosion/corrosion. In low pH oxidising environments the effects of the two mechanisms are synergistic: the rate of material removal is greater than the sum of erosion and corrosion taken separately. This is because the corrosion of the matrix in the alloy is accelerated by the continuous removal of the protective passivating film due to the impact of the solid particles in the slurry. The rate at which the passive layer can be replenished determines the ultimate rate of material removal.

Passive layer formation is governed to a large extent by the level of chromium in the alloy matrix. Chromium levels above 16% have been shown to give the best oxidation resistance [1].

Ultrachrome® A51

Typical white irons such as Warman Ultrachrome® A05 (ASTM A532 Grade 3A) consist of a hard carbide phase in a ferrochromium matrix. The M_7C_3 chromium carbide has a hardness of 1400 -1600 HV and is largely responsible for the excellent erosion resistance of these irons. The ratio of carbide to chromium in the alloy determines the amount of carbide phase which is formed and the residual chromium in the matrix. The iron and chromium levels in the matrix and the quantities of other alloying elements present determines the type of stainless steel and thus the corrosion resistance.

To improve the corrosion resistance of these white irons the chromium content was increased to the maximum practical level. This resulted in an alloy with a largely ferritic stainless steel matrix, hard carbides and an overall bulk hardness of 450 HBW. This new alloy, Ultrachrome® A51 has a hypoeutectic microstructure with primary ferrite dendrites and a eutectic comprising finely dispersed eutectic carbides in a matrix of eutectic ferrite. Typical microstructures for a range of stainless steels and A51 are shown in Figure 4.

The combination of a relatively high volume fraction of hard carbides and a corrosion resistant ferrite stainless steel matrix makes the performance of A51 exceptional when compared with either white irons or stainless steels in acid slurries. A51 also contains copper, molybdenum and nickel as alloying elements to ensure that the matrix offers optimum pitting resistance.

Lab Testing

The A51 alloy has undergone extensive testing during its development. Laboratory tests have included: static immersion (ASTM G31) and potentiodynamic (ASTM G59 and G61) corrosion tests and disk wear tests [2].

Through this extensive testing it was found that the corrosion rate for A51 was significantly less than that for typical white irons and was in fact very close to that for duplex stainless steels. In synthetic 28% phosphoric acid solutions, corrosion rates of both the stainless steels and A51 are generally very small (less than .01 mm/a). This is negligible compared to the effects of erosion. It is probably arguable in most phosphoric acid slurry applications that erosion (rather than corrosion) is the dominant factor and ultimately the cause of part failure.

Laboratory wear testing of materials with fine particle slurries is very difficult because materials like gypsum are not only fine but also quite soft. Tests which recycle slurry are not accurate because particles very quickly become degraded. Corrosion then becomes the dominant material removal mechanism. With a "once-through" process stream, as mentioned above, erosion should dominate. To avoid problems of particle attrition, Warman typically use silica sand as an erosive medium in their wear tests with a very short residence time.

Comparative wear and corrosion data for some different stainless steels and A51 are shown in Figure 3.

Potentiodynamic corrosion tests for a range of stainless steels and A51 are shown in Figure 5. In 28% phosphoric acid at 80°C, A51 exhibits a large passive region and with only a small hysteresis loop in the cyclic polarisation curve indicating that the metal surface repassivates quickly.

The effects of impurities in the phosphate rock need to be considered also. Some phosphate ores have quite high fluorine levels which can dramatically effect the corrosion levels in metals. Figure 6 shows the effect of different fluosilicic acid concentrations on corrosion rates of A51 at different temperatures. As a guide, A51 should not be used where the average fluosilicic acid concentrations exceed 0.5%.

Patent

Ultrachrome® A51 is part of a family of alloys which are currently subject to Warman patent applications in a number of countries. So far they have been allowed for patent grant in both the U.S.A. and Australia.

Field trial results

Over the last 3 years Warman have conducted extensive field trials with A51 in a number of plants in Florida, Europe and Australia. The major applications trialled have been on filter feed, flash cooler and gypsum removal. Typical duty data and comparative part lives for these applications are shown in Table 2. As can be seen A51 has given an improvement in life of between 2 and 10 times over either the stainless steels or elastomers that it replaced.

CONCLUSION

The Warman pump with its completely interchangeable materials philosophy is the most practical for making use of different materials. The ability to mix material classes including elastomers, white irons and stainless steels in the one pump is essential to achieving the most cost effective life from the pump. Warman's new alloy, Ultrachrome® A51, gives a significantly improved wear life over alternative stainless steels even in the most arduous slurry duties in phosphoric acid plant service. As a complete pump impeller and lining material, or mixed with Neoprene or Butyl liners, A51 should provide the basis for significantly lower pump ownership costs.

ACKNOWLEDGEMENTS

The assistance of John Maras and Bob Phillips of Arroyo Process Equipment in drawing Warman's attention to the need for the new alloy, and their support for the subsequent trialling of A51 is gratefully acknowledged.

REFERENCES

[1] Tomashov, H.D., "Theory of corrosion and protection of metals", Macmillan Co., N.Y., (1966)

[2] Huggett, P.G. and Walker, C.I. "Development of a wear test to simulate slurry erosion", Proc. of HYDROTRANSPORT 11, BHRA, Cranfield, U.K., (1988).

Material	Warman Code	Hardness	Max. Temp. (C)	Composition	Related Standards
Alloy 20	C25	130 HBW	*	Min C, 20 Cr, 29 Ni	ASTM A743 Grade CN – 7 M
CD-4 MCu	C26	250 HBW	*	Min C, 25 Cr, 5 Ni	ASTM A351
Ferralium† 255	C55	250 HBW	*	Min C, 25 Cr, 5 Ni (N)	ASTM A240
UNS Nº 8028	C30	150 HBW	*	Min C, 27 CR, 31 Ni	ASTM B668
Butyl	S21	60 Shore A	100	Halobutyl + fillers	–
Neoprene	S42	50 " "	100	Poly Chloroprene + fillers	–

* temperature depends on concentration of phosphoric acid

† Ferralium® is a registered trademark of Langley Alloys Ltd. (UK)

TABLE 1 Typical materials used for phosphoric acid applications

SERVICE	PUMP SIZE	SLURRY	DUTY	PART	LIFE (hrs)	COMMENTS
FLASH COOLER	550 TUL	28% P_2O_5	H = 41 ft.	TUL55147A51	7 000 +	Still in progress
		40% $CaSO_4$	Q = 18 000 gpm	U55041A51		" " "
		SG = 1.7		UL55083A51		" " "
		T = 185° F		TUL029A51		" " "
	550 TUL	28% P_2O_5	H = 43 ft.	TUL55147A51	10 000 +	Still in operation
		40% $CaSO_4$	Q = 12 000 gpm	TUL55147C30	24 000	Weld repaired
		SG = 1.65		UL55083A51	8 900 +	Still in operation
		T = 185° F		UL55083S42	3 000	Erratic due to tearing
				UL55083C26	5 000	Local holing
	650 TUL	28% P_2O_5	H = 30 ft.	U18041A51	3 700 +	Still In operation
		40% CaSO4	Q = 32 000 gpm	UL65083A51	"	" " "
		SG = 1.63		TUL65147A51	"	" " "
		T = 180° F				
FILTER FEED	10/8 FAH	28% P_2O_5	H = 71 ft.	G8041A51	4 900 +	Still in operation
		40% $CaSO_4$	Q = 3 400 gpm	G8083A51	"	" " "
		SG = 1.63		G8110A51	"	" " "
		T = 185° F		FAM8147A51	"	" " "
	8/6 FAH	28% P_2O_5	H = 75 ft.	F6041A51	2 500 +	Still in operation
		40% $CaSO_4$	Q = 1 600 gpm	F6083A51	8 000	Average life
		SG = 1.63		F6083S42	1 900	Erratic due to tearing
		T = 185° F		F6083C55	2 300	Local holing
				F6147A51	9 000	Average life
				F6147C55	6 000	Average life
	8/6 FAH	28% P_2O_5	H = 70 ft.	F6041A51	4 200 +	Still in operation
		40% $CaSO_4$	Q = 1 700 gpm	F6083A51	"	" " "
		SG = 1.7		F6147A51	"	" " "
		T = 185° F		F6110A51	"	" " "
GYPSUM TAILINGS	12/10 STAH	22% CaSO4	H = 170 ft.	G10147A51	11 300+	Expect 3 000 hrs more
		pH 1 – 2	Q = 6 800 gpm	G10147C55	4 500	Average life
		SG = 1.15		G10147U01	3 600	–
		T = 110° F		G10083A51	6 200+	Still in operation
	8/6 THH	20% $CaSO_4$	H = 300 ft.	GH6041A51	6 000	Estimated life
		pH 1 – 2	Q = 4 000 gpm	GH6041C55	2 300	Local holing
		SG = 1.13		GH6083A51	6 000	Estimated life
		T = 110° F		GH6083C55	2 300	Local holing
				GH6110A51	6 000	Estimated life
				GH6147A51	6 000	" "
				GH6147C55	4 000	Local holing
ACID TRANSFER	4/3 CSC	54% H_3PO_4	H = 56 ft.	43053JA51	14 000+	Still in operation
		SG = 1.65	Q = 400 gpm	43053JC30	6 000	–
		T = 85° F				

TABLE 2 A51 material trial results in phoshoric acid slurries

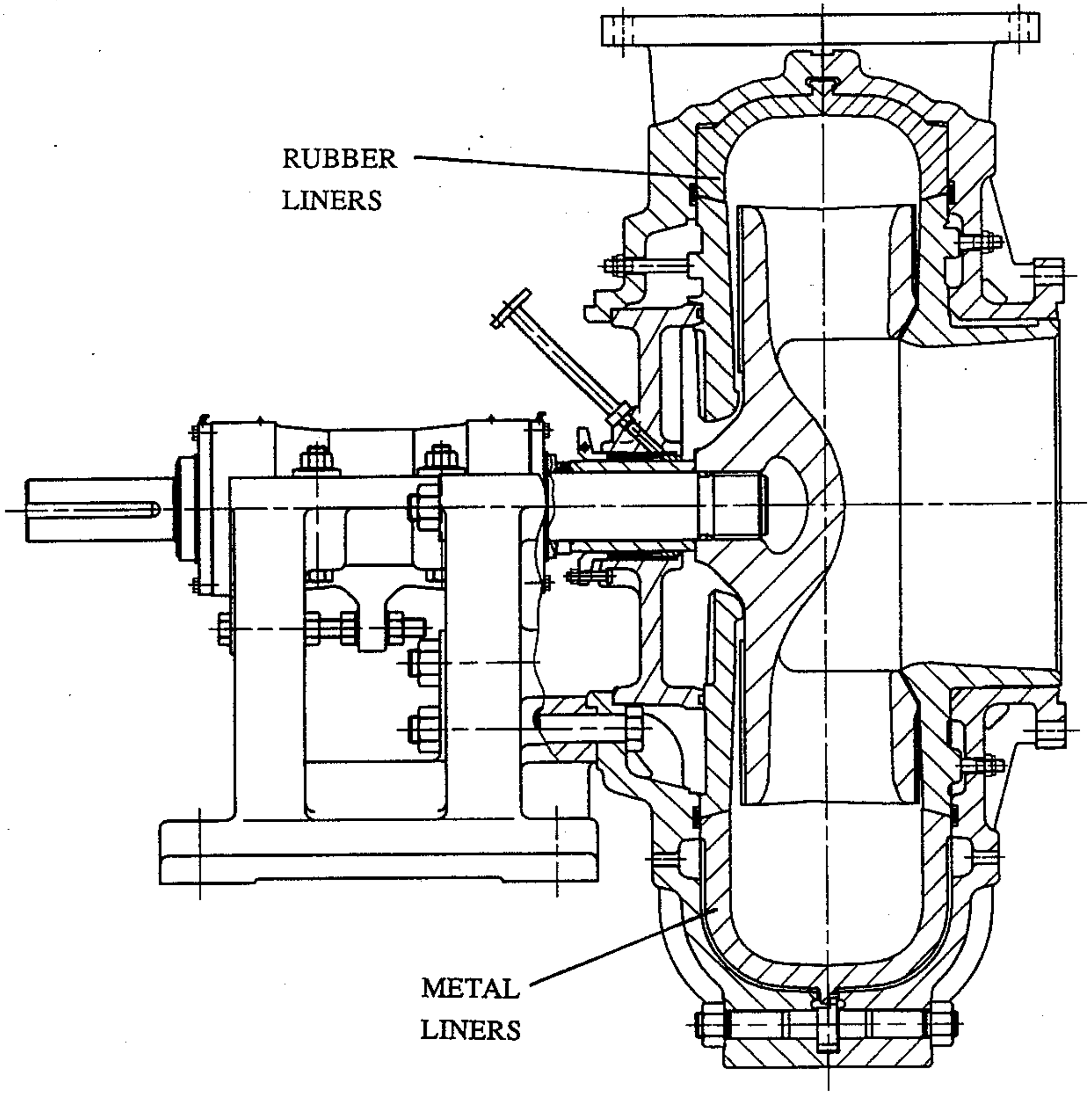


Figure 1. Warman 650L pump with interchangeable metal and elastomer liners

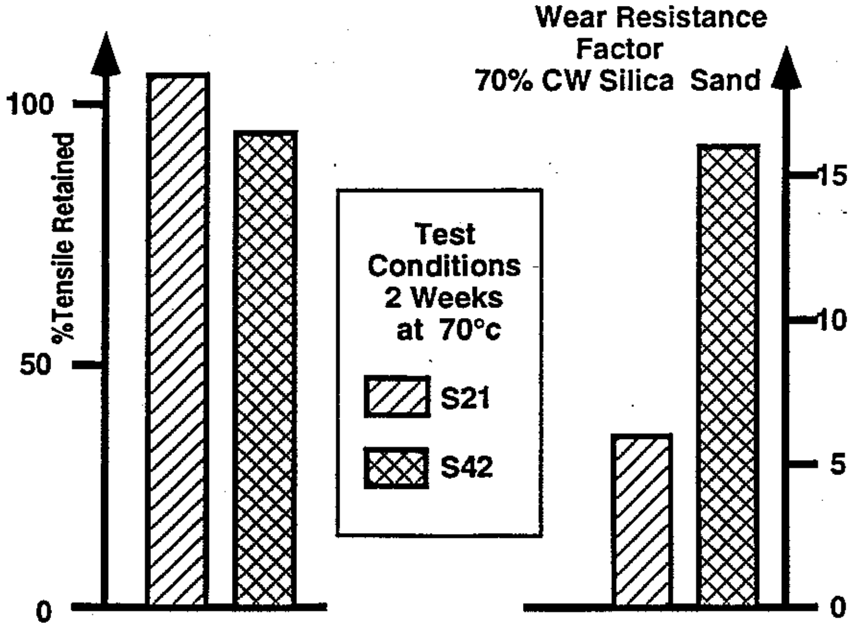
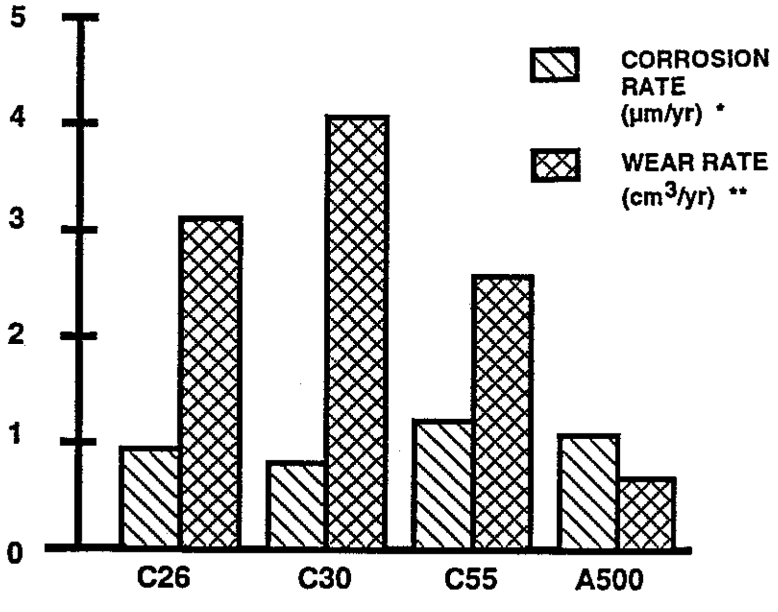
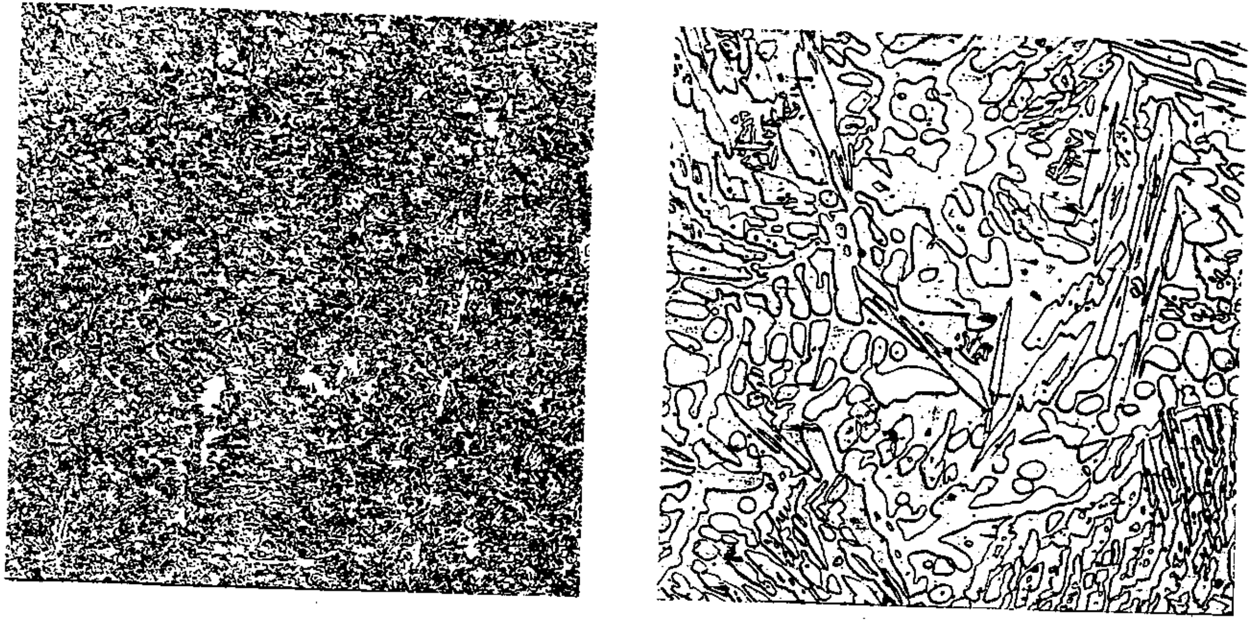


Figure 2. Effect of 20% phosphoric acid containing 2% sulphuric acid on Butyl (S21) and Neoprene (S42) elastomers



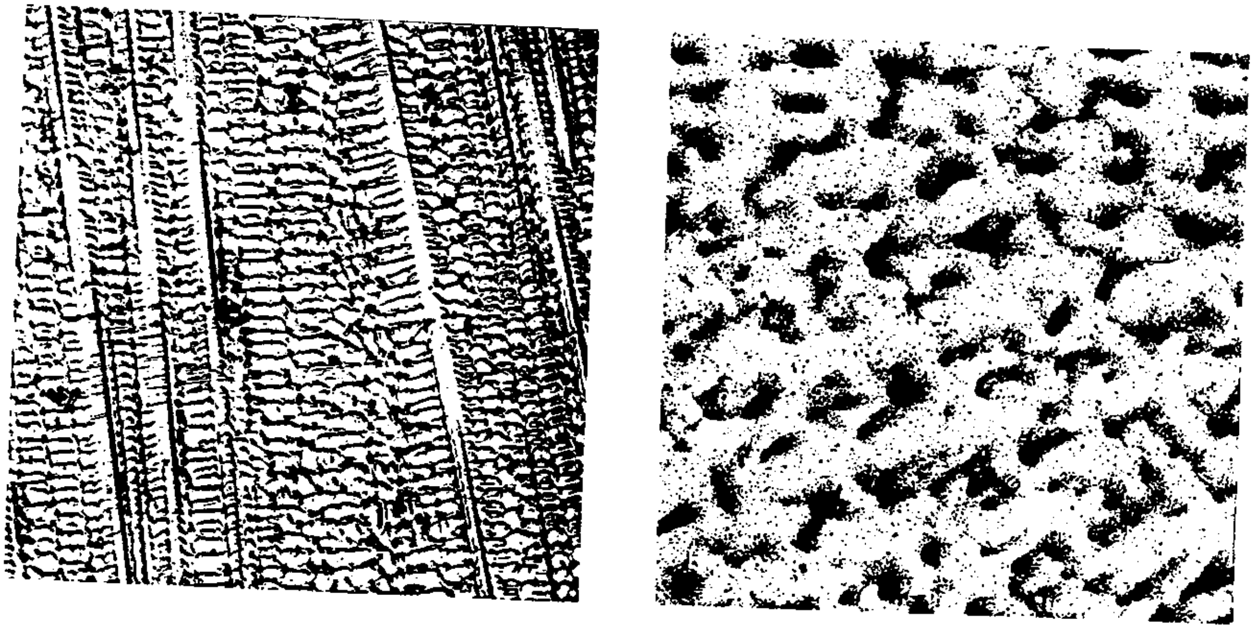
* 28% Phosphoric Acid, 80°C
** Disc Wear Tester, 20% CV, River Sand.

Figure 3. Comparison of stainless steels with Ultrachrome® A51



a) Ultrachrome® A51

b) Stainless Steel C55



c) Stainless steel C30

d) Stainless Steel C25

Figure 4. Microstructures of different alloys for phosphoric acid service

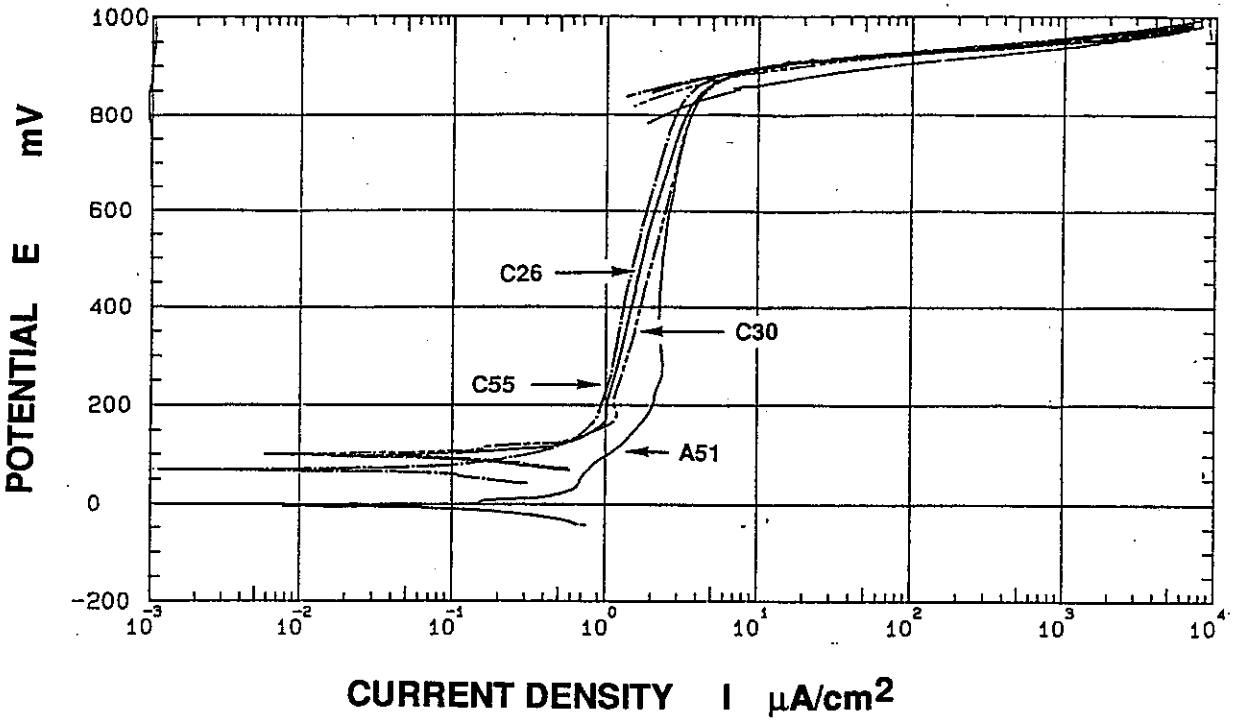
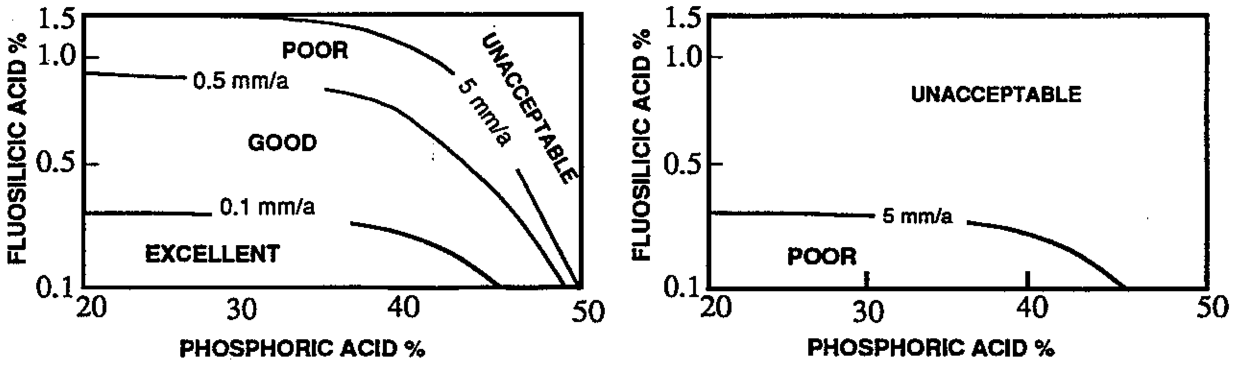


Figure 5. Potentiodynamic cyclic polarisation plot for different alloys in 28% phosphoric acid at 80°C



(a) Temperature = 50°C

(b) Temperature = 95°C

Figure 6. Corrosion resistance of A51 in phosphoric acid with 3% sulphuric acid and fluosilicic acid