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EDITED BY A.F. GIFFORD

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FOREWORD

Successful process plant operation owes much to the work of the materials and joining engineers and the initial conceptual and detail designer. Between them, they provide a team which is committed to providing plant which will produce its intended product reliably, safely and economically, and be easily made and installed on time. There have been few previous seminars where such a spectrum of materials and processes associated with the design and manufacture of process plant equipment has been discussed in such detail.

Process plant equipment covers a number of industries and products, each demanding specialist attention to the selection of materials, fabricating and joining processes. The need was therefore recognised to bring together the experts, who each make their own industries possible and thus help to provide the creature comforts and foods we find so essential in this modern world.

The many skills involved in building process plant resulted in the symposium addressing a very broad range of technology. This collection of papers provides current information on the following:

a) A variety of welding and cutting processes, with a major contribution on the increasing role of expert systems and computers in providing control mechanisms, both for manufacture and for design operations.
b) The importance of ceramics, recognising continuing problems of brittleness.
c) High quality stainless steel and nickel alloys, meeting many industrial needs.
d) Surface treatments used to resolve tribological and corrosion problems.
e) The benefits to be gained by surface conditioning, i.e. 'peening' as a means to combat fatigue, stress corrosion cracking (SCC) and corrosion fatigue.
f) The increasing use of plastics, arising from improved joining techniques, but limited at present to relatively low temperatures.

Finally, the advent of expert systems will enable the skills of specialists in welding and allied technologies to be encapsulated and will ensure that knowledge becomes even more readily accessible in the future.

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SESSION I:
Developments in materials

PAPER 1

Developments in metals — an evolving plant fabrication technology

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SUMMARY

While no sweeping technological changes could be said to have taken place during the major economic recession in the process plant industry of the past decade, improved fabricating methods have been implemented to meet the enhanced quality assurance requirements of the users. Demands by the process industry are increasingly for more complicated plant designs with more dimensional precision and for plant for service conditions requiring improved alloys in severely corrosive service conditions. This paper reflects the way in which the demands have been met in applying metals to severe service environments.

INTRODUCTION

With some notable exceptions, the initial requirement when selecting a metal of use in the process plant industry is that it should have adequate corrosion resistance at the service temperature with minimum price.

When the choice of metal or alloy has been made a second requirement is to select the design, fabrication and quality assuring methodology that gives an adequate safety factor in service at lowest cost.

By reference to specific recent examples of fabricated process plant, this paper addresses the second of these requirements where the corrosive media are such that carbon steel and the more conventional stainless steels have inadequate corrosion resistance.

The ultimate user is subjected somewhat to the competing claims for superiority of these metals by their suppliers. More often than not the choice is clear cut but beware the user whose economic choice is made by the unit weight cost of the metal alone. Consideration of density, required metal form, quantity involved and of fabrication cost factors are essential. Cost comparisons have been made elsewhere (1-4).

A summary of the metals and alloys under review is given in Table 1, and their main application areas in Table 2.

APPLICATION AND SELECTION

Aggressive media which cause problems to the process industries that are of most concern are:-

Inorganic acids notably sulphuric, nitric, phosphoric, hydrofluoric acid.
Organic acids notably acetic, benzoic and terephthalic.
Concentrated alkalis notably potassium hydroxide.
Sea water
Corrosive gases notably chlorine and sulphur dioxide.

Metals or alloys which are appropriate at a particular level of medium concentration, temperature, purity or aeration, may of course not be suitable at higher levels of these variables. Furthermore, certain media/metal combinations require an awareness of the dangers of stress corrosion cracking, crevice corrosion, corrosion fatigue, pitting corrosion and grain boundary corrosion.

While there are good rule-of-thumb broad selection procedures, the complexity of variables tends to make material selection for severely corrosive environments largely empirical supported by plant trials where a new process application is envisaged. One such recent example is the material requirement for flue gas desulphurisation (FGD) plant with its potential for large scale use of one or more of the several contending alloys for resistance to corrosion by wet sulphur dioxide and high chloride, low pH solutions (5-8).

Significant improvements have been made in alloy development over recent years. Notable introductions are included in Table 1 viz.

Nickel alloys

Alloy G.3 With improved ductility over alloys C276 and alloy B2 it is more easily fabricated and corrosion resistant in hot sulphuric, phosphoric and nitric acids.

Alloy G.30 An alloy with applications in strongly oxidising acids and commercial phosphoric acids, it is superior to alloy G and alloy 625 for this purpose.

Alloy H Particularly cost effective and having suitable stress cracking resistance in FGD plants, it is resistant to stress corrosion, cracking, pitting and crevice corrosion.

Alloy C22 Claimed to have better overall corrosion resistance than alloy C276, alloy C4 and alloy 625 it resists localised corrosion particularly in chloride containing solutions and strongly oxidising media.

Titanium alloys

Ti Grade 12 A 0.8% Ni 0.3% Mo alloy which has widely substituted for the price unstable Ti 0.2% palladium alloy favoured for corrosion resistance in more reducing conditions than can be withstood by unalloyed titanium 'Fig. 1'. The significantly higher strength of this alloy at all service temperatures is as yet insufficiently appreciated. It is very cost effective where this can be taken advantage of in reducing wall thickness. The comparisons of 'Figs. 2 and 3' shows its allowable stress values and yield/-density ration compared with commercial purity titanium.

A pressure vessel application in a recent major US chemical plant with an economic comparison has recently been reported (9). Its application as a lid lining is shown in 'Fig. 4'.

Ti Grade 9 A promising newcomer derived from the widely applied aircraft industry alloy with 6% - Aluminium 4% vanadium but having 3% Aluminium and 2½% vanadium - with a major strength benefit over unalloyed titanium 'Fig. 2'. It is currently being considered by the ASME code authority.

In the fabrication of pressure plant in these metals, the prevalent welding process used is gas tungsten arc welding which, while experiencing no substantial change in use over the past two decades has seen a trend to mechanisation particularly with hot wire feed 'Fig. 5,' and to specialised welding equipment for specific joint types particularly tube end to tube plate welds of heat exchangers. Synergic MIG welding is receiving much attention as is the use of orbital pipe welding with inserts. More significant perhaps is the implementation of quality planning and monitoring to a rigidly controlled quality assurance system - the latter nowhere more strict than in the environmentally sensitive area of plant for nuclear waste reprocessing. The implementation of total quality management will receive further impetus by the product liability legislation of the Consumer Protection Act of 1987.

While having no direct influence on material selection, the fabrication industry has the ensuing problems of:

- designing out potential areas for corrosion
- ensuring that economic forming and welding procedures are in place as new alloys are introduced
- creating confidence in the client that quality assurance systems for the new alloys are of an adequate standard

With this background, representative examples are given next of process plant in various alloys to illustrate design solutions, and fabrication procedures necessary to produce high integrity containment of aggressive fluids at elevated temperatures and pressures.

SOME FABRICATION AND WELDING APPLICATIONS

Nickel alloys

A straightforward design and fabrication application in the recently introduced alloy G3 is the vapouriser drum to ASME VIII Div 1 of 'Fig. 6'. This alloy is increasing in usage, its higher molybdenum and nickel content conferring more resistance to corrosive attack in mixed acid solutions than the more generally used alloy 825. Requirements were that the heads after forming should be solution annealed at 1149°C with rapid cool and that seams be fully X-rayed and dye penetrant checked. A typical weld joint preparation is shown in 'Fig. 6'. An increasingly common requirement, as in this case, is that positive metal identification (PMI) be part of the quality plan for vessel construction. PMI is often a requirement of third party inspection both at material suppliers, and at the fabricator during and after manufacture.

The catalyst regenerator vessel in alloy 600 of 'Fig. 7,' is a good example of the increasing complexity of vessels that is now being demanded; as in this case for a chlorination process at 540°C. Provision is made in the design for catalyst to be continuously top fed into an annular space between two cylindrical slotted screens and for reaction gas, regenerate gas and purge air to be passed radially through the screen at different process intervals. As well as needing a finely detailed assembly procedure and welding sequence, tight tolerances on the finished dimensions were required. Statistical analysis involving over 200 screen and annular space measurements were taken in horizontal and vertical vessel orientation to ensure compliance and low service downtime due to catalyst abrasion, screen blocking and hot spot screen burnout.

In general, welding procedures were that weld root runs were by GTAW followed by MMA filler runs. Alloy 600 weld overlay on ASTM A182 FI by the automatic hot wire GTAW process was used on blind flanges. Extensive dye penetrant testing, ultrasonic testing and spot radiography was a requirement.

An example of a complicated form of high temperature tubular heat exchanger is the gas heater of 'Fig. 8,' in which shielding of the tubeplate of a shell and tube heat exchanger from hot shell inlet gas is by use of Alloy 600 in the vulnerable positions coupled with ceramic shields cast into position during construction around the type 347 stainless tube plate. The ceramic cement insulates from the hot entry 925°C gas and equalises the temperature both across the tubeplate thickness and around its periphery. The cooler tube-side inlet gas enters in the peripheral tubes and then reverses direction radially towards the centre line of the bundle passing out at around 520°C into the inner channel end. Differential expansion of the inner channel outlet as it penetrates the outer channel wall is accommodated by an alloy 600 bellows. The tubes were hydraulically expanded into the tube sheet after welding.

Hydraulic expansion of tubes into tubeplate which was a feature of this heat exchanger is now increasingly used in high integrity shell and tube heat exchangers in preference to the more conventional roller expansion method (10, 11). In this method the tube deforms plastically by applied hydraulic pressure against the inside of the hole; a method which makes it particularly suitable for thin walled tubes. A comparison shows that little or no work hardening occurs in the hydraulic expansion method compared to the significant hardening of the tube by roller expansion. There is also little or no wall thinning by this method. Care must be taken in setting the expansion length to avoid bursting or ballooning of tubes behind the tubesheet. The operation is shown in 'Fig. 9'.

Complexity and close dimensional tolerances occasionally necessitate the fabrication of vessel sections in separate jigs to restrain any movement out of shape and size during welding. In the vertical wet scrubber column of 'Fig. 10,' each of seven sections each with an integrally welded bubble cap tray was fabricated in a jig so as to maintain +/- 0.5mm verticality on each section. This was followed by trial fitting to the bottom section which was closely packed with coilwork. Then the sections were welded together in the vertical position on site such as to maintain a +/- 2mm verticality tolerance. Non destructive testing included extensive radiography, fibre optic inspection and helium leak testing.

In 'Fig. 11,' an example is shown of an added complication where it was required that a column be fully dressed with trays cabling, insulation, and deck platforms before leaving the works for site.

When the design conditions permit, it is still economical to loose-line steel vessels with the more costly nickel alloys such as alloy C276 as in 'Fig. 12'. Because nickel alloys are fusion compatible to steel it permits a technique of panelling the vessel interior by edge fusion to the vessel walls with a suitable disimilar metal GTAW process filler metal and then obviating the weld metal dilution effect on corrosion resistance by applying alloy C276 sealing strips with edge fillet welds to cover these joints as illustrated. This wall paper concept is expected to have widespread application in FGD systems.

Titanium

Some sizeable vessels have now been fabricated in titanium although economy dictates that section thickness be low. As a recent example of the large titanium vessels now being applied, the titanium vessel of 'Fig. 13,' has unusual design requirements for an internal bed frame to carry non-metallic material. Design was for 130°C in ASME B265 Grade 2 commercial purity titanium and a 1 hour working cycle between 27 and 110°C. Designed to be as economically thin as possible, PREVPAK micro computer design software was invaluable for calculations of local loads and the stresses at the saddle support. The design solution gave shell thickness of 7.5mm in the saddle area 6.35mm elsewhere, and external stiffening rings for general support, the vessel being allowed to expand freely on the saddles via a PTFE sandwich interlayer. Local loads on the end pipework due to vessel expansion were subject to theoretical stress analysis. As in this instance, local load calculation demands on fabricators are now commonplace. With thirty upright titanium pipe supports welded via pads to the shell, extensive internal and external argon shielded backing was required.

It is becoming the practice that the tubes of titanium heat exchanger bundles be expanded into the tube sheet by the hydraulic expansion method. In a typical instance each 14 swg grade U-tube is expanded into two grooves over a 200mm length into a 222mm thick titanium tubeplate. Expansion procedure test blocks were required as were daily test weld samples before start of production welding. A helium leak test from the shell side is a further requirement and the usual ferroxyl test for freedom from iron contamination before welding is necessary. To prevent tube scoring and service vibration, PTFE ferrules are used in the baffle holes.

Zirconium and tantalum

A heat exchanger is now under construction with 9 inch thick zirconium tubeplates, but explosively clad zirconium to mild steel tubeplates are more usual 'Fig. 14'.

With these few exceptions, because of its higher cost, zirconium tends to be used in thin sections, for example as vessel internals, linings and coils. Much skill is required in satisfactory lining not only to get a close fit in intricate designs but because it is, like titanium and tantalum, not ferrous fusion compatible. The zirconium clad agitator of 'Fig. 15,' involves painstaking piecemeal fitting and argon shielding to protect the sheet metal joints. Stability of the cladding is conferred by a number of zirconium plugs through blade holes which are seal welded to the sheet on each surface.

Sheet thickness used in the more expensive tantalum is lower still although it is sometimes used in explosion clad form. A welding chamber installation for tantalum shielding is shown in 'Fig. 16'.

SPECIALISED WELDING PROCESSES

Two of the less common welding methods now being applied are mechanised and enhanced versions of GTA Welding, which is still the dominant process for high integrity work. These are:-

Hot wire TIG welding

Used principally for productivity gains by high deposition without sacrifice of high weld soundness. It is also useful for the weld surfacing of steel with, for example, nickel alloys. Hot wire TIG by virtue of its speed needs longer trailing and backing shields than normal welding and careful weld parameter setting to achieve weld pool deposition equilibrium with traverse speed 'Fig. 4'. It is of course more economical as weld thickness increases. The less common metals are not used often in thick section so that welding machine capital cost is not easy to justify unless batch production or lengthy runs are a feature of the work. Nevertheless one can expect increasing application of the process in the future.

Back face or down-the-bore welding

Used for welding heat exchanger tubes to the rear face of tube plates in order to avoid the natural crevice present with front face welding, there is some productivity gain in this process by automation of the weld cycle and by saving of the length of tube otherwise needed to pass through the tubeplate thickness.

The major gain is that of ensuring the highest integrity by the ability to radiograph what is effectively a butt weld.

Back face welding requires much perseverance in setting the weld parameters, procedures and positional requirements. This is in order to achieve adequate penetration at the rear of the weld on each tube exterior so that a concave underside fillet is obtained for a smooth external joint and no crevice is caused by inadequate penetration. An example of welds obtained by this technique using commercially available equipment is shown in 'Fig. 17'. It is currently being applied in heat exchangers for the nuclear waste reprocessing industry and the fertiliser industry.

The fabrication sector with which this paper is concerned operates in a high material and high weld cost regime with weld soundness requirements well above those achieved by the flux shielded processes that have the advantage of higher linear speeds and higher deposition rates. In compensation for the relatively high weld costs, repair costs are remarkably low in GTA welding these metals. The challenge for welding engineers in this sector remains to maintain the present high standards of weld soundness and integrity while increasing the weld production rate towards that achieved in the ferrous process plant sector.

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Table 1 Alloy designations and compositions

NICKEL ALLOYS

GENERIC NAME	ASTM NO.	WERKSTOFFE NO.	APPROXIMATE COMPOSITION %					
			Fe	Ni	Cr	Mo	Cu	Minor Elements
Alloy 28	B709	1.4563	35	31	27	3.5	1.3	
Alloy 20	B463	2.4660	34	38	20	2.4	3.4	0.6Nb
Alloy 825	B163	2.4858	28	41	21	6.1	2.2	0.8Ti
Alloy G	B582	2.4618	19	45	22	6.4	2.0	2.0Nb
Alloy G3	B582	2.4619	19	48	23	7	2.0	0.3Nb
Alloy H	-	-	19	48	22	9	-	2.0W
Alloy G30	-	2.4603	15	45	29.5	5.5	2.0	2.5W, 08Nb
Alloy 690	B168	2.4642	9	61	29			0.25Ti
Alloy 600	B163	2.4816	9	73		16		0.25Ti
Alloy C276	B575	2.4819	6	57	16	16		3.5W
Alloy C22	B575	2.4602	4	57	21	13		3.2W
Alloy C4	B574	2.4610	3	66	16	16		0.3Ti
Alloy 625	B443	2.4856	2	63	22	9		3.4Nb
Alloy 400	B127	2.4360	2	64			32	
Alloy B2	B333	2.4617		69		28		
90:10 CuNi	B706	2.0872	1.5	10			88	0.7Mn
70:30 CuNi	B715	2.0882	0.6	30			68	0.7Mn
Nickel 200	B160	2.4068		100				0.08C max
Nickel 201	B160	2.4610		100				0.02C max

TITANIUM GRADES AND ALLOYS

GENERIC NAME	ASTM NO.	APPROXIMATE COMPOSITION %								
		N max	C max	Fe max	O max	Al	V	Pd	Ni	Mo
Grade 1	B265	0.03	0.10	0.20	0.18					
Grade 2	B265	0.03	0.10	0.30	0.25					
Grade 3	B265	0.05	0.10	0.30	0.35					
Grade 7	B265	0.03	0.10	0.30	0.25			0.2		
Grade 9	B265	0.03	0.08	0.30	0.25	3	2.5			
Grade 12	B265	0.03	0.08	0.30	0.25				0.7	0.3

ZIRCONIUM

GENERIC NAME	ASTM NO.	APPROXIMATE COMPOSITION %			
		Hf max	C max	Fe max	O max
Zr702	B551	4.5	0.05	0.2	0.16

Table 2 Principal applications

NICKEL ALLOYS

GENERIC NAME	SULPHURIC ACID	HYDROCHLORIC ACID	NITRIC ACID	PHOSPHORIC ACID	SEA WATER	SO_2 FLUE GAS	ALKALIS	CHLORINE	ORGANIC ACIDS	HYDROFLUORIC ACID	SOME TRADE NAMES*
Alloy 28	X			X	X	X					Nicrofer 3127LC
Alloy 20	X										Nicrofer 3620NE, Carpenter 20
Alloy 825	X	X		X			X				Incoloy 825, Nicrofer 4221
Alloy G	X			X							Hastelloy G, Nicrofer A520hMo
Alloy G3	X			X							Hastelloy G3
Alloy H						X					Nicrofer 4823hMo
Alloy G30				X							Hastelloy G30
Alloy 690			X				X				Nicrofer 6030
Alloy 600							X	X			Inconel 600
Alloy C276	X			X		X		X	X		Hastelloy C276, Nicrofer 5716
Alloy C22	X	X							X		Hastelloy C22, Nicrofer 5621
Alloy C4	X			X		X					Hastelloy C4, Nicrofer 6616, Coronel C4
Alloy 625	X			X		X					Inconel 625, Cabot 625, Nicrofer 6020hMo
Alloy 400					X		X		X	X	Monel 400
Alloy B2		X									Coronel B2, Hastelloy B2, Nicrofer 6928
90:10 CuNi					X						Kunifer 10, Cunifer 10
70:30 CuNi					X						Kunifer 30, Cunifer 30
Nickel 200							X			X	
Nickel 201							X	X			
TITANIUM GRADES AND ALLOYS											
Grade 1			X		X	X		X	X		IMI 115, Ti 35A
Grade 2			X		X	X		X	X		IMI 125, Ti 50A
Grade 3			X		X	X		X	X		IMI 130, Ti 75A
Grade 7			X								IMI 260, Ti Pd
Grade 9			X								-
Grade 12			X		X						Ti Code 12, IMI 325
ZIRCONIUM											
Zr702	X	X	X				X		X		

* Trade name attributions - Hastelloy (Cabot Corporation)
Nicrofer, Cunifer (VDM Metal Technology AG)
Inconel, Incoloy, Monel, Coronel (Wiggin Alloys)
IMI 115, Kunifer etc (IMI plc)
Ti 35, Ti Code 12 (Timet Corporation)