Stainless steel for durability, fire-resistance and safety

By G. Waller & D.J. Cochrane

Economic and safety aspects of stainless steels

Since the industrial age began, the safety of structures and the protection of human life have been matters of paramount importance to engineers. Despite two centuries of accumulated experience, those same issues remain of major concern today. Perhaps because mankind's ambitions sometimes exceed his current skills, accidents still occur and continue to take their toll. New technologies pose new problems and occasionally the unforeseen happens, with far-reaching and tragic results.

Fire is one of the most dangerous hazards. The widespread storage and handling of inflammable liquids and gases mean that a mere spark can be enough to create a conflagration or provoke an explosion. So when industrial complexes are being planned, the closest attention must be given to the problems of preventing, containing, limiting and extinguishing fire. This includes studying the available materials and making the best and safest choices for the key fire-risk areas and personnel evacuation routes.

COMPARATIVE FIRE TESTS

To assist designers and engineers in this task, the Nickel Development Institute joined with the International Chromium Development Association and three stainless steel makers (Avesta AB, British Steel Stainless, and Ugine) to sponsor an independent programme of fire tests on four materials commonly used in land-based and offshore structures. These were galvanised mild steel, glass-reinforced plastic (GRP), aluminium and austenitic stainless steel Type 316 (UNS S31600). Details of the test procedures and results are on pages 4-6 of this booklet.

The tests demonstrated clearly that stainless steel structures can be expected to maintain their integrity even after prolonged exposure to the highest temperatures reached in hydrocarbon fires, whereas GRP and aluminium provide relatively little resistance to fire because of their low melting points. Galvanised mild steel can withstand fire for a useful period but suffers some loss of rigidity and may drip molten zinc, constituting a possible hazard to personnel.

This favourable result for stainless steel is not surprising in view of the widespread use and long experience of this type of material in high-temperature industrial processes and equipment. Nevertheless, comparative tests under controlled conditions were considered advisable to establish the order of superiority that stainless steel demonstrates over alternative materials in severe fire conditions.

LIFE-CYCLE COST STUDY

In parallel with these tests, the U.K. Steel Construction Institute was asked to examine the economics of stainless steel structures vis-a-vis those made from other materials. This involved computing the first cost and, importantly, the ongoing costs arising from maintenance, repair and replacement over the likely life-cycle of each structure. A summary of the findings appears on pages 6-8 of this booklet.

The calculations show that the relatively high material cost of stainless steel is counterbalanced by its long corrosion-free life and virtual freedom from maintenance and repair, making its true economics much more attractive than might at first appear. Indeed, it is likely to be substantially less costly over a 10-30 year life than galvanised mild steel, which was the only other material tested that demonstrated a useful degree of fire resistance.

Additional safety usually carries some financial penalty in the short term. The information provided by the fire test programme and the economic study suggests that the greater use of stainless steels in selected areas of onshore and offshore structures could significantly enhance fire safety at an acceptable cost.

Stainless steel cladding, as used for this British Gas platform in Morecambe Bay, ensures long trouble-free life, minimum maintenance and outstanding resistance to fire.

Courtesy of British Gas plc

Worldwide uses of stainless steels

Steels resistant to rusting were first developed about 75 years ago when the effects of adding substantial amounts of chromium to steel were being investigated. These early chromium-rich steels looked highly promising, combining a bright surface appearance with what was then regarded as outstanding resistance to corrosion. In practice, their usefulness proved to be restricted because they were not amenable to hot- and cold-working and could not be formed readily into the bar, plate, sheet and other forms needed to construct industrial equipment. These limitations were overcome by adding nickel to the chromium steels; this much improved their fabrication characteristics and further enhanced their corrosion-resistance.

During the 1920's a definitive composition for a versatile rust-free steel was established. This was the `18-8' type so familiar today, containing 18% chromium and 8% nickel. Commercial production soon followed and the popular name `stainless steel' came into general parlance. One of its first major uses was for the Art Deco-style spire of the Chrysler Building built in New York City in 1929; it involved cladding the upper 88 m of the 320m high structure. Today, more than six decades later, the spire remains among the city's finest sights as it catches and reflects the changing sunlight, bearing striking testimony to the longevity and visual appeal of stainless steel.

The 1930's saw notable expansion in the use of ‘18-8’ type stainless steels. Significant markets began to open up as the news spread of their excellent resistance to many types of corrosive media and their freedom from maintenance when exposed for long periods in atmospheric conditions. Among the industries which first exploited the benefits of the new materials were petrochemical production, power generation, food processing and handling, transport and architecture. The range of uses steadily extended as practical experience was gained and confidence grew.

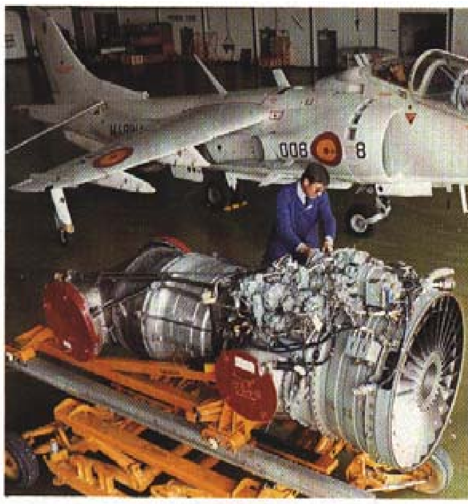
Further expansion occurred during World War II but it was in the post-war era that the rate of growth accelerated rapidly. The impetus came firstly from the modernisation and restructuring of traditional industries, followed by the advent of advanced technologies and, latterly, the ever-rising aspirations of the world's peoples as regards living standards, health care and environmental concerns. All these impulses called for superior constructional materials capable of ensuring safety, long trouble-free life, freedom from deterioration and minimum maintenance. These are the very qualities that the stainless steels provide.

Many grades of chromium-nickel stainless steel are now available to meet specific needs, but the basic ‘18-8’ type (now designated Type 304 or UNS S30400) is still utilised in substantially greater quantities than any of the newer variants. Its good corrosionresistance, ease of cleaning, ability to withstand both heat and extreme cold, strength, toughness and good fabrication behaviour make it the standard material for countless applications. Examples are petrochemical equipment, food and beverage production, medical equipment, road and rail transport, paper and pulp manufacture, liquid-gas handling and storage, nuclear components and structures, pharmaceutical production, architectural facades and roofing, domestic kitchen equipment and street furniture.

Wherever service conditions are unusually stringent, one or more specialised types of stainless steel are available to provide enhanced performance. A good example is the widespread and successful use of Type 316 (UNS S31600) stainless steel in the aggressive chloride-laden conditions of marine service. Particular needs such as superior corrosion-resistance, easier fabrication, improved weldability, maximum strength-weight ratio or good cold-working behaviour can be met by suitably alloyed stainless steels. Advice on the most appropriate grade to use is obtainable from stainless steel manufacturers or from the Nickel Development Institute.

Swedish railcar fabricated entirely from stainless steel (18% Cr 9% Ni). The body has a strong cross-section of arc-welded beams with longitudinal side-beams at floor and ceiling level. Roof and side panels are corrugated and the poor is pattern rolled for further strength.

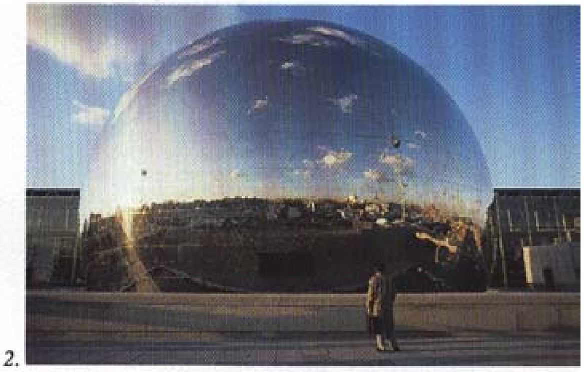
Courtesy of ABB Traction, Sweden



1.

1. *Lightweight all-stainless steel insulation encloses the bifurcated jet pipe of the vectored-thrust 'Pegasus' engine used in the 'Harrier' vertical take-off aircraft.*
Courtesy of Rolls-Royce plc

2. *The 'Geode' in the Parc de la Villette, Paris, France, is an impressive 36m diameter sphere clad with 6,443 triangles of Type 316 stainless steel cut from some 80 tons of sheet.*
Photo: F. Chabrolle



Courtesy of Darchem Engineering Limited

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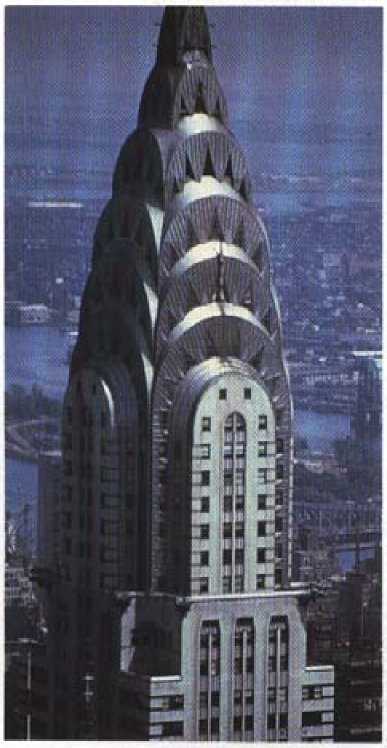


3. *Stainless steel cladding of the top 88m of New York's Chrysler Building is still in bright condition after 60 years' exposure.*

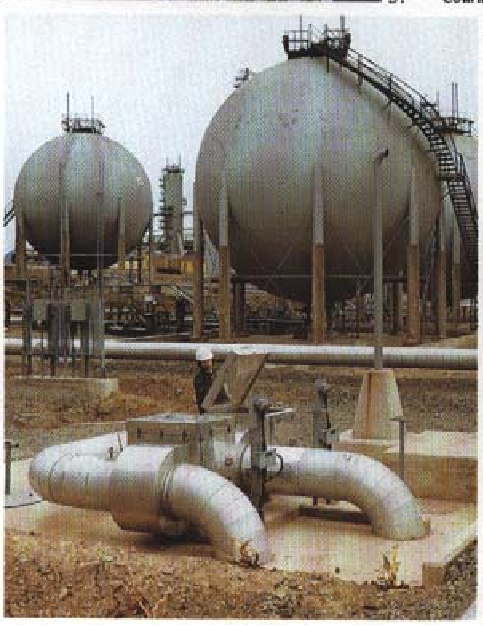
4. *Extensive use of various grades of stainless steels is made by the nuclear power industry to meet stringent safety and performance requirements.*
Courtesy of NNC Limited

5. *A stainless steel fire protection box for an emergency shut-down system at a chemical plant. In fire tests this type of enclosure was exposed to flame temperatures around 1000°C for over 15 minutes. The maximum inside face temperature reached only some 170° C.*

3.

Courtesy of Darchem Engineering Limited

4.



5.

6. *Liquefied natural gas (LNG) at –162° C being supplied to the tanker 'Polar Alaska' through stainless steel Type 304L transfer and deck piping.*

6.

Tests prove the superior fire resistance of stainless steels

To obtain comparative data on the behaviour of four familiar structural materials when exposed to serious fires, Darchem Engineering Limited (a NAMAS-approved testing laboratory) was commissioned to perform a series of controlled tests on cable ladders obtained commercially. The candidate materials were glass-reinforced plastic (GRP); aluminium; galvanised mild steel; austenitic stainless steel Type 316 (UNS S31600).

FIRE RESISTANCE TEST

Modern electric cables have intumescent coatings to provide self-protection for the conductors if a fire occurs. These coatings expand in a fire, become brittle and cannot withstand much bending. Cable ladders should therefore be made of material that will not deform excessively at high temperatures, thus avoiding damage to coatings.

The test procedure involved ladders of 3-metres length being uniformly loaded* to simulate the weight of cables and directly heated by 18 LPG burners adjusted to give average temperatures of 1000-1050° C for 5 minutes.

Results

GRP: The GRP ladder collapsed before all the burners were ignited and no meaningful temperature measurements were possible. Ignition of the ladder material was observed together with the emission of fumes.
Aluminium: The aluminium ladder suffered total structural failure after 26 seconds, too short a time for meaningful temperature readings to be obtained. No molten metal was seen because the rapid collapse due to softening caused the ladder to fall outside the fire zone.

Galvanised Mild Steel: The mild steel ladder maintained its integrity for the required 5 minutes. Large globules of molten zinc were seen to fall as the test proceeded. Maximum average temperature recorded was 642° C and the maximum individual ladder temperature was 811° C.
Stainless Steel: The stainless steel ladder maintained its integrity for the required 5 minutes and, without shutting off the burners, it was decided to continue the test. After a further 40 minutes the test came to an end when the bottled gas supply ran out. Throughout the full 45 minutes the stainless steel ladder maintained its integrity. Maximum average ladder temperature reached was 705° C and maximum individual ladder temperature was 757° C. The average flame temperature exceeded the specified 1000° C for 14 minutes.

RADIATION RESISTANCE TEST

In fire situations, structures may be heated by radiation rather than by direct flame impingement. To simulate this condition, each ladder was uniformly loaded as in the previous test and then exposed to direct radiation from above in an electrically-heated cabinet. The tests were continued until either the ladder temperature stabilised or structural failure occurred.

Results

GRP: The GRP ladder suffered total structural failure after 6 minutes. Average ladder temperature at failure was 185° C with a maximum individual temperature of 222° C.
Aluminium: The aluminium ladder suffered total structural failure after 12 minutes. Average ladder temperature at failure was 238° C and the maximum individual temperature was 264° C.

** The aluminium ladder, purchased to the same nominal specification as the other three ladders, was found to be of thinner material section. It was therefore loaded only sufficiently to provide similar initial deflection, ie. 455 kg against 609 kg for the other ladders.*

Aluminium ladder before and after fire resistance test. The ladder collapsed 26 seconds after the burners were ignited.

Top left: GRP ladder after fire resistance test. Total collapse occurred before all burners were alight. Smoke and fume emissions were noted.

Top right: Aluminium ladder after radiation resistance test. Structural failure occurred after 12 minutes of radiant heating.

Galvanised Mild Steel: The mild steel ladder maintained its structural integrity throughout the 2 hours taken to reach temperature stability. Average ladder temperature at the end of the test was 552° C with a maximum individual temperature of 557° C. By the end of the test the entire zinc coating of the ladder had disappeared, although only one globule of molten zinc was observed to fall.

Stainless Steel: The stainless steel ladder maintained its structural integrity throughout the 3 hours taken to reach temperature stability. Average ladder temperature at the end of the test was 556° C with a maximum individual temperature of 565° C. The deflection of this ladder after 3 hours was only slightly more than one-third that of the galvanised steel ladder after 2 hours.

CONDUCTION THROUGH FITTINGS TEST

Observations of actual installations have shown that although cable ladders are protected from fire, the support legs are very rarely insulated. This can provide a heat path around the fire protection. Tests were therefore made on aluminium and stainless steel ladders wrapped with 100 mm of ceramic fibre insulation and supported on unprotected legs. Each ladder was fitted with one stainless steel and one galvanised mild steel leg. No test of aluminium legs was made because it was thought improbable that these would ever be fitted to protected ladders.

Each ladder contained 12 cables butted against its sides in two groups of six and was loaded, as in previous tests, to simulate the remaining cables. Three cables on each side were connected to an integrity meter indicating three fault conditions : open circuit; earth fault; cable-to-cable fault, ie. electrical resistance breakdown between cables. One cable each side was thermocoupled.

The test procedure was to control the burners for flame temperatures in the 1000-1050° C range and monitor cable integrity and temperature. Two criteria for failure were set : (a) that cable integrity be maintained for 15 minutes, and (b) that cable temperature remain below 95° C for 15 minutes.

Results

Aluminium: The aluminium ladder suffered progressive collapse and consequent cable integrity failure in less than 5 minutes. Initial collapse on the galvanised leg side occurred in just over 2 minutes and partial collapse on the stainless leg side just over 1 minute later. Total collapse of the ladder took 4 minutes and 41 seconds.

Bottom left: Galvanised mild steel ladder after fire resistance test. Structural integrity was maintained for the stipulated 5 minutes, at which time central deflection was 166.5 mm. Globules of molten zinc were seen falling during test.

Bottom right: Stainless steel ladder after fire resistance test (extended to 45 minutes, see text). Structural integrity was maintained throughout test and central deflection was only 80.5 mm at conclusion.

Stainless Steel: The test criteria were fully met and the test was continued beyond the stipulated 15 minutes. Cable integrity failure occurred at 26 minutes on the stainless leg side and 33 minutes on the galvanised leg side. The cable temperature climbed above the stipulated 95° C after 21 minutes on the stainless leg side and 26 minutes on the galvanised leg side.

CONDUCTION THROUGH WALLS TEST

In some installations where cable ladders pass through walls, there is a possibility that sufficient heat could be transferred from a fire on one side of a wall to create a hazard on the other side. Tests were therefore made on a rig simulating a cavity wall, with the cavity insulated, penetrated by a cable ladder and being subjected to a severe fire on one side only.

Aluminium and stainless steel ladders were tested, each 2-metres long with a joint in the centre fitted with a splice plate. For the test, each ladder was positioned with the splice plate at the point of penetration of the wall. Flame temperatures were set at 1000-1050° C and the test was continued until the temperature stabilised on the "cold" side of the wall.

Results

Aluminium: The aluminium ladder suffered total collapse by melting on the "hot" side after 1 minute 8 seconds. However, since the end of the ladder protruding from the wall was still exposed to flames, the test was continued. After 37 minutes the temperature had stabilised on the "cold" side at 134° C on one ladder web and 152° C on the other web.

Stainless Steel: The stainless steel ladder remained in unchanged condition throughout the test, which was terminated at 90 minutes when temperatures on the "cold" side of the wall had stabilised. The temperatures recorded were 80° C on one ladder web and 58° C on the other.

Evaluating the true costs of stainless steel structures

An independent study of the structural applications of stainless steels offshore has been conducted by the U.K. Steel Construction Institute at the request of the Nickel Development Institute, the International Chromium Development Association and three stainless steel producers (Avesta AB, British Steel Stainless, and Ugine). It complements the fire-test programme summarised on pages 4-6 by identifying specific areas of offshore platforms where the fire-resistance, strength and corrosion-resistance of the stainless steels can be beneficially exploited, and analysing the economic consequences of choosing stainless steel rather than mild steel or aluminium.

Structures selected for detailed evaluation were stairways, ladders, walkways, handrails, gratings, floor systems, firewalls, blastwalls, and cladding for modules and corridors. Cable ladders were excluded because stainless steel is already established offshore for this application. Other uses suggested but not costed were helidecks and flare booms.

All design criteria used in the study conformed to British Standards Codes of Practice, Department of Energy guidelines and American Petroleum Institute (API) recommended practice for offshore platforms. The direct-cost elements studied were materials procurement, fabrication, surface protection, repair, replacement and cleaning. Indirect costs were also considered, especially the substantial savings that may arise from the use of maintenance-free materials.

Left: Accommodation module for the Hutton tension leg (TLP) platform, clad with stainless steel.
Courtesy of Conoco (U.K.) Limited

Right: Firewall fabricated with stainless steel profiled cladding.
Courtesy of Darchem Engineering Limited

COSTING TOPSIDE STRUCTURES

The three materials considered were mild steel to BS 4360 Grade 43C or equivalent; aluminium to Grade 6082TF; and stainless steel Type 316L. Evaluation was on the full-life cost basis using information from suppliers and fabricators working in the offshore industry. Assumptions on maintenance schedules and costs were made on data provided by operators responsible for the day-to-day running of offshore facilities.

Allowance was made for the fact that offshore fabrication is covered by very tight specifications involving higher levels of weld inspection and weld repair than are required onshore. Also, labour is much more expensive offshore, primarily because of the costs of transportation and providing living quarters aboard offshore platforms.

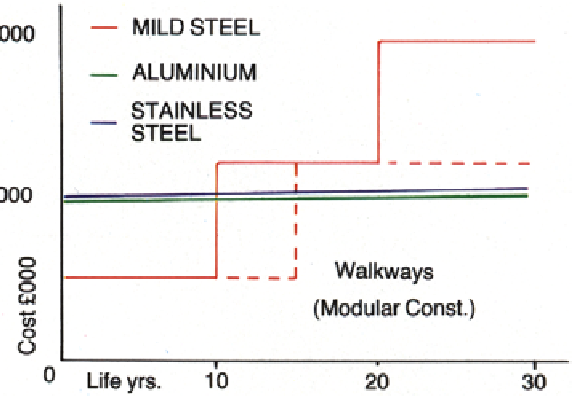
MAINTENANCE AND CORROSION

In estimating the frequency and cost of maintenance, the key factor is the likely corrosion behaviour of the structural materials in the harsh conditions of offshore service. Fortunately, there is a wealth of long-term experience on which to draw.

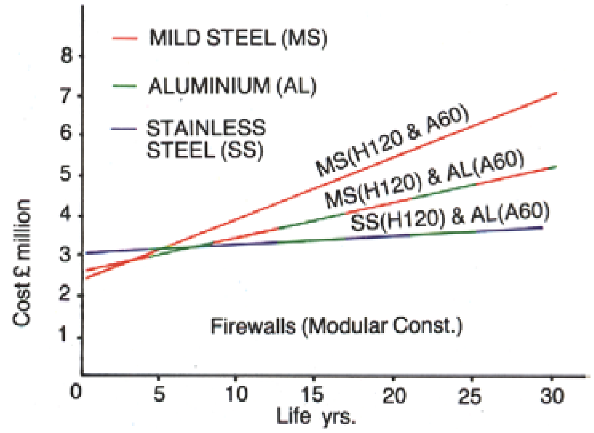
Mild Steel:- Unprotected mild steel is known to corrode in the chloride-laden marine environment at around 0.15 mm per year per exposed surface, which if allowed to continue will soon lead to severe weakening. For example, a 6-mm-thick I-section beam would lose half its capacity in only 10 years. Hence it is essential that protective paint layers are maintained intact throughout the life of the structure. While details of offshore maintenance contractors' schedules vary, the study conservatively assumes complete repainting every 5 years. When repainting is properly and regularly performed, mild steel can be expected to last the full life of the structure and require no replacement. Galvanised mild steel, on the other hand, will probably last 10 to 15 years depending on the severity of the environment. It may then need complete replacement. Consequently the study gives replacement costs for both 10- and 15-year lives.

Aluminium:- Corrosion rates of aluminium are low and usually limited to surface pitting. The study assumes a wash-down every 6 months to reduce the rate at which this occurs. The chief source of concern with aluminium alloys is galvanic corrosion, aluminium being anodic to both mild and stainless steels. When connecting aluminium to mild-steel modules or around stainless steel piping, it is essential to provide electrical separation of the two metals or the aluminium will corrode preferentially. If joined to galvanised mild steel, aluminium will first cause corrosion of the zinc coating and then itself corrode.

Stainless Steels:- For use offshore the recommended grade is not the familiar ‘18-8’ type but the more highly alloyed Type 316, usually in its low-carbon version designated 316L. This material maintains its protective chromium-rich oxide layer even in severe chloridecontaining atmospheres and provides high resistance to surface pitting and crevice corrosion over a long service life. For all practical purposes it can be regarded as



Estimated costs over a 30-year life cycle of walkways for a North Sea modular platform with a topside dry weight of 20, 000 tonnes.



Estimated costs for the same platform of firewalls having fire ratings of H120 in process areas and A60 in accommodation areas.

having zero corrosion and being maintenance-free. The study assumes washing at 6-monthly intervals to reduce surface staining and tarnishing, but in practice this is not essential.

DIRECT-COST COMPARISONS

On the basis of direct costs alone, the study finds that the relatively low first-cost of mild steel structures is soon offset when the life-cycle maintenance and replacement costs are taken into account. The changeover point occurs at the time when the first replacement of mild steel becomes necessary. Aluminium structures, while significantly more expensive than mild steel, are shown to be somewhat cheaper than those of stainless steels at the materials costs obtaining in early 1989. Both aluminium and stainless steel are normally regarded as maintenance-free offshore apart from an infrequent wash-down.

PRODUCTION LOSSES DURING MAINTENANCE

An indirect cost consideration which cannot easily be quantified is the effect that required maintenance work such as welding, shot-blasting and repainting may have on production. Whenever welding is performed in hazardous areas, production of oil or gas is halted and the environment is checked for explosive gases before work commences. The cost of each lost day amounts to

Courtesy of Rocco Products Ltd.

The Royal Navy Type 22 frigate 'HMS Sheffield', commissioned in 1988, embodies four stainless steel stairways and numerous other functional and decorative components in the same material.

Crown Copyright picture

millions of dollars for a large platform. Grit or shot blasting are classified as 'hot working' and are considered a potential fire risk unless production is closed down.

Most platforms have an annual shut-down period for routine maintenance to proceed. For a moderate-size oil-producing platform it could typically be 10 days per year. For each day of lost production of perhaps 70,000 barrels of oil at, say, $18 per barrel the lost revenue would be $1,260,000. It follows that even the saving of just one day of one shut-down period would largely recoup the extra costs of specifying maintenance-free stainless steel rather than mild steel for structures like ladders and walkways.

OTHER POTENTIAL COST SAVINGS

Maintenance-free elements in a structure offer the possibility of scaling-down the size of accommodation and facilities for maintenance crews, hence reducing weight and cost during platform construction. Another weight-saving factor is that stainless steel does not require the 'corrosion allowanc' of mild steel and can therefore be used in thinner sections.

In the current economic climate of lower oil prices and development of marginal fields, unmanned satellite platforms are being considered. Trouble-free materials will be of special importance in these structures because of the limited scope for accommodating maintenance teams.

	Modular	Integrated
Mild Steel	811.525	444.825
Stainless Steel	604.480	308.680
Weight saving, tonnes	207.045	136.145
Weight saving, %	25.5%	30.6%

Two types of North Sea platform, one of modular construction and the other an integrated deck, were considered in the Steel Construction Institute study. This comparison of the total weights involved highlights the savings realised by the use of stainless steel structures.

FIRE RESISTANCE

Having shown that mild-steel structures are the lowest in first-cost but the highest in life-cycle costs, and noted that aluminium structures are currently cheaper than those of stainless steel, the study comments on the relative safety of the three materials in fire conditions. It points to the `very poor fire resistance' of aluminium compared with mild steel and the stainless steels, citing its low melting point (660° C) and serious loss of strength at temperatures as low as 200° C. By contrast, the stainless steels have melting points around 1400° C and retain useful strength up to the highest temperatures likely to be attained in hydrocarbon fires.

Attention is drawn to the potential risk of molten aluminium dripping from topside structures during a fire emergency and the similar risk of molten zinc (melting point 420° C) dripping from galvanised mild steel. The study also notes that stainless steels require no painting and cannot therefore give rise to the toxic fumes sometimes given off by burning paint on mild steel structures. The overall conclusion reached is that the stainless steels have demonstrably better fire-resisting properties than aluminium or mild steel, making them safer materials in a fire.

CONCLUSION

The fire tests and study of life-cycle costs together demonstrate that the stainless steels are cost-effective materials offering a greater degree of safety than GRP, aluminium or mild steel (galvanised or painted).

Compared with mild steel, lightweight stainless steel structures reduce topside weight, enhance fire-resistance and virtually eliminate the need for maintenance.

Maintenance onshore and offshore is costly, disruptive of production, and sometimes hazardous. The wider deployment of stainless steel will therefore yield significant economic benefits as well as providing levels of fire safety unequalled by alternative materials.

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