APPLICATION OF STAINLESS STEELS IN NUCLEAR TECHNOLOGY

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SINCE the advent of nuclear technology, stainless steel has found new applications not only because of its properties of superior corrosion resistance and strength, but also because of its superior behaviour with respect to ionizing radiation. As a result stainless steel is the most important material of construction that finds use both in the production of nuclear pure materials and in the construction of nuclear reactors.

In chemical plants for separation and purification of materials of nuclear purity various acids and alkalies are used and stainless steel, because of its high resistance to corrosion, is widely used as a structural material. Thus pulse-type stainless steel extraction columns are used for purification of uranyl nitrate solution and in radiochemical separations[1,6]. Type 316 is used when chlorides or sulphates are present, and for higher temperature operation a higher alloy steel such as Type 309 is desirable. Reduction of UO_3 to UO_2 is carried out in stainless steel (Type 347) furnaces wherein the operation is carried out at a temperature of about 1200°F. in a current of hydrogen. The majority of tanks and vessels used in uranium production are of some type of stainless steel, glass-lined construction being the only alternative. Welded tanks using Type 321 or 347 have proved entirely satisfactory for mild corrosive conditions or where no chlorides are present. For handling acid solution containing chloride tanks made of Type 316 are preferred. These tanks, however, must be properly heat-treated to preserve the corrosive resistance of the welded parts. Further, the quality of the welds, particularly on equipment that is to be heat-treated, must be very high as any pinholes or slag inclusions will generally be exposed by the annealing and pickling procedure[2]. In the case of unannealed tanks of Types 302 and 304, regions around the welds are rapidly attacked by copper, nickel and iron salts in their high valence or oxidized state even in alkaline solutions. Where annealing cannot be done, adequate corrosion resistance may be obtained by polishing.

A lot of stainless steel is used in process piping. Types used are 316, 321 and 347. 302 and 304 are not preferred. From general considerations and economics Type 316 is good for such work. As mentioned before, heat treatment of the weldment is essential. It may also be mentioned in this connection that the best non-welded construction that may be adopted in such cases is the use of ferrule fittings[2].

With the need to withstand pressures of the order of 2000 p.s.i. required for the operation of certain type of reactors, like the pressurized water reactor and the boiling water reactor, and also the higher temperatures which are necessary for good thermal efficiency in power reactors, stainless steel is widely used as a reactor structural material. This is despite the rather unfavourable neutron absorption cross-section of stainless steel. Thus Type 347 is used for the reactor vessel (containing enriched uranyl nitrate or sulphate solution) and cooling tubes of the water boiler type of reactors such as SUPO or LOPO. In certain cases, as in the sodium graphite reactor, Type 347 stainless steel is used for canning of fuel element.

With the use of liquid metals as coolant in power reactors materials having resistance to erosion and dissolution by the liquid metals are required. Among the liquid metals, low melting metals such as lead, bismuth and their alloys are promising as coolants for use in power reactors. Aluminium cannot be used as a material of construction because of low melting point, whereas another possible metal, zirconium, reacts with lead and bismuth. Research data[3] show that it is possible to use Type 321 under certain conditions. Interaction between this and liquid bismuth, lead and their alloys occurs at a temperature of 900°-1100°F. which results in the alteration of the mechanical properties of steel. Also the steel becomes magnetic after prolonged interaction with the alloy, and this has been ascribed to the change in the structure from austenite to ferrite, which results due to the leaching of one of the constituents, namely nickel, by the lead-bismuth alloy. It has been noted that special addition of inhibitors such as nickel, calcium and barium reduces the interaction between the eutectic alloy and the steel. The presence of Ni (0·6 per cent) in the eutectic Pb-Bi alloy preserves steel from attack of the liquid alloy somewhat better than the presence of calcium and barium in the same alloy.

Sodium, sodium-potassium alloys are also used as coolants in some reactors. Oxygen content[4] of these metals is quite an important factor in corrosion and with 18-8 stainless steel and other ferrous alloys of interest for high temperature structural application, penetration rates of 0·1 mil./year (0·0025 mm./year) or less are readily achieved if the oxygen content of the sodium is kept low enough (less than 0·001 per cent). For service with mercury[5] nickel-free steels appear to be the best since nickel is much more soluble than iron in mercury, and nickel seems to be selectively dissolved out of alloys which contain it, e.g. austenitic 18-8 type. For mercury boiler tubes (where a certain degree of high temperature strength and oxidation resistance are concerned) the material most commonly used is Sicromo stainless steel (Croloy 5 si) containing 5 per cent Cr, 0·5 Mo, 1·5 Si. It may also be mentioned in passing that inhibition of corrosion in the case of ferrous alloys (Ni-free) in contact with mercury is carried by additions of Mg or Ti (1 to 10 p.p.m.).

In areas where there is danger of floor contamination and where losses of uranium must be held at an absolute minimum, special materials of construction for floors are used. Where there is no trucking or heavy traffic such as in laboratory, tygon flooring and heavy linoleum have proved satisfactory. For production areas where the service is more severe continuous metal-clad floors are most effective in preventing losses. The problem of installing welded stainless steel floors which do not buckle and feel firm to the tread is solved by welding the stainless steel plate to backing bars imbedded in the concrete flooring[2]. Sixteen-gauge stainless steel with a 2B commercial finish is used for these installations. The backing bars are $2 \times \frac{1}{2}$ in. carbon steel rods installed in the concrete with a maximum spacing of 24 in. Quarter inch half-holes punched along the edge of the sheet at 6 in. intervals are used to plug-weld the sheet to the backing bars. An $\frac{1}{8}$ in. butt weld can then be made between the sheets and the welds ground smooth without danger of buckling stainless steel. The areas covered with stainless steel are provided with curbing and thresholds which retain any major liquid spills within the area. All curbing, equipment foundations and pipe thimbles are provided with core bases which aid in cleaning the floor.

Process equipment or structural materials which have been exposed to radioisotopes will always pick up a certain amount of activity as a result of surface adsorption of radioactive material[6]. During the process, the equipment may become so contaminated that it is impossible to get close to it for maintenance or repair work, even if the radioactive contents are removed. Under these conditions one may be faced with the choice of either decontaminating the equipment to remove radioactivity or replacing it with new units. Thus in radiochemical work two additional criteria for evaluating materials of construction are the susceptibility of the surface to contamination and the ease with which the material can be decontaminated to a permissible radiation level. The surfaces used for this work must be smooth and non-porous, non-ionic (minimum chemical exchange), resistant to corrosion by acids, alkalies and organic solvents and should have some degree of heat resistance. Stainless steel is almost exclusively used for the construction of radiochemical processing equipment because of its corrosion resistance, some structural properties and relative ease of decontamination. Other common structural materials, such as concrete, lead, plain-carbon steel, do not decontaminate as well as stainless steel.

Commercial materials for the construction and control of nuclear equipment are evaluated not only by the effects of heat and atmosphere on the various properties, but also by the effect of bombardment by nuclear particles during the process of irradiation. An increasing amount of attention is being paid to steels in regard to their resistance to radiation damage, particularly with respect to strength and ductility characteristics. The results of research show that in general carbon steels as well as stainless steels, nickel and cobalt base alloys show higher yield strength, a reduction in ductility, a decrease in creep rate; electrical resistivity and density changes are only slight. Precipitation of ferritic phase occurs in austenitic stainless steel, but the amount of ferrite precipitate is insufficient to cause concern in regard to the stainless character of these alloys.

Finally, a brief mention must be made of the welding that is so commonly used in the fabrication of these steels. For some of the equipment in nuclear technology very high perfection in the weldment is expected. According to a recently declassified report of U.S. A.E.C., for a long time Type 347 was used almost exclusively and a number of service problems and delays in delivery of equipment were traced to the welding behaviour of the alloy. Cracking both in the weld metal and in the heat-affected zone of the weld metal was the major problem. It was found that cracking was due to a combination of a defective welding technique and a faulty choice of welding rod. According to the report, Type 304L has served in many applications as an alternate to Type 347. It can be used as-welded under ordinary corrosive conditions at temperatures up to 800°-900°F. Above this range its strength is considerably less than that of Type 347 and corrosion resistance much lower. In welding Type 304L none of the welding difficulties encountered with Type 347 have been encountered. For inert gas-shielded arc Type 308L is used as a filler material. At present when welded assemblies must be made from stainless steel that is resistant to sensitization, the A.E.C. recommends first an all-Type-304L weldment. If corrosion conditions are severe, 304L base metal is welded with Type 347 welding rod for extra protection of the weld area. When either operating stress or service temperature is too high for Type 304L, an all-Type-347 assembly is selected. To reduce cracks associated with Type 347 weld metal, welding rods that will deposit a two-phase structure with about 4-8 per cent ferrite in the austenitic matrix are used.

References

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