Welding Problems with Steels used on Chemical Plants

By O J DUNMORE*

Introduction :

You will all know that problems abound in welding —if it were not so, welding engineers would be less in demand than they are now. The type of problem I am going to talk about is not the sort that you meet every day such as excessive slag inclusions (due to a lazy welder), porosity (poor quality electrodes), lack of fusion (incorrect current setting), incomplete penetration (wrong joint design) etc., etc., These are all familiar problems and it is not necessary for the welding engineer to draw on his knowledge of metallurgy to be able to solve them successfully. However, there are a number of welding problems which are met less frequently but when they are met can be very intractable. Generally, they involve cracking either during welding or in subsequent service and a knowledge of metallurgy is invariably needed to solve them.

Hot Cracking of 347 Type Stainless Steel i.e. 18/8/1 Cr-Ni-Nb.

A few years ago, this type of steel was chosen for the superheated steam headers on the most advanced super critical steam boilers being installed in the U. K. After a few months in service, there occurred frequent cracking of welds. Initially these were repaired by grinding out and re-welding, but failure again occurred at the repaired welds. A very thorough investigation was then carried out by BWRA into the problem.

Electron microscope examination of the failed welds showed that there was a fine precipitate of niobium carbide within the grains of the heat affected zone. Away from the heat affected zone, this precipitate was not present. Also in the H.A.Z. of newly welded test pieces the precipitate was absent. This suggested that the cracking and the occurence of the precipitate were associated—especially as the cracks were confined to the area where the precipitate was at its heaviest. A test piece was then devised to simulate the welding condition i.e. heavy restraint during weld deposition and was heated for different periods at various temperatures to simulate conditions.

Cracking of the test weld occurred when the temperature of re-heating was below 800°C and the lower the temperature the longer was the time required for cracking. Below about 500°C, the time required for cracking becomes greater than 10 years ; so, for practical purposes, this is the lower limit of danger.

A similar but less marked tendency was found for 18/8 Ti and non-stabilised steels. (Fig. 1).

The most interesting finding was that 18/10 Mo did not crack at all because it did not have any intergranular precipitate formed in the H.A.Z.

Other metallurgical examples are known where the presence of dislocations (i.e. atomic discontinuities) which are produced in a metal lattice when it undergoes plastic strain, nucleates precipitate particles of another phase. In the absence of the strain and dislocations there is not sufficient free energy available to allow the

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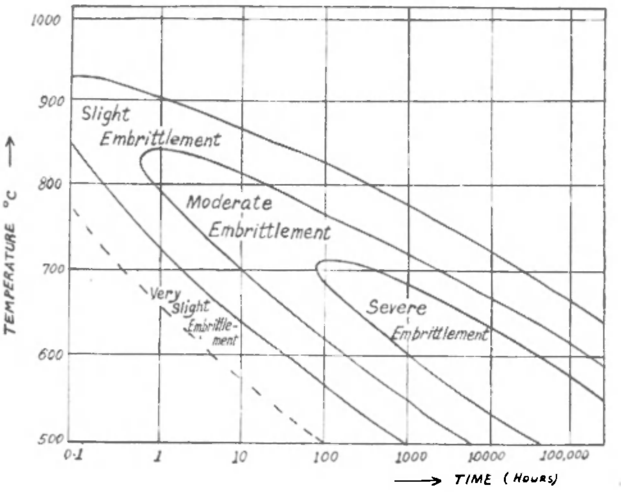

Fig. 1.

precipitate to form. Once the grains are strengthened the weakest region becomes the grain boundary which then cracks.

The importance of the strain requirement is that the welding problem with 18/8 Nb steel did not become apparent until the welding involved heavy sections, (i.e. wall thickness over ½″). Another case is known to the writer where some 2½″ W.T. 347 steel cracked during the stress relief heat treatment.

The obvious solution to this problem is therefore to avoid the use of 347 type stainless steel except for thin (½″) sections not involving high service temperatures. 316 should be always used if the service temperature is greater than 450°C.

If the problem is met with and it is not possible to change the material the two best remedies are to :

(a) Use 316 for re-welding after removing the original welds. The material has a lower hot yield strength than 347 and therefore the weld metal yields before the heat affected zone.

(b) Heat treat the equipment at about 950/1000°C —rapidly heating through the embrittlement temperature range ; this eliminates the local strains. Frequently these measures are effective but they are not as reliable as using the correct material in the first place. The only field where 347 has a real advantage is against nitric acid corrosion where it has definite benefits over the other grades of stainless steel. For other uses it should be avoided.

Therefore if the steel stockist offers 347 type of stainless steel as a substitute for the type which was ordered, accept it with caution.

Cracking of C—½ Mo Steel

This is a type of cracking which occurs during or immediately on completion of welding. It is generally confined to the H.A.Z. near the fusion line.

There have been frequent reports of cracking with this material when making restrained welds and some manufacturers of equipment always use the more expensive 1% Cr-Mo instead. In all cases that have been examined in detail by the writer, high carbon contents were involved although they were not always high enough to have been out of specification. The basic trouble is that to achieve a given strength level more carbon is needed in C-½ Mo than 1% Cr-Mo and the steel maker is tempted to work near the top of the carbon specification for the former. As most fabrication codes do not recognise this, the preheat used may be as low as 100°C and hard zone cracking becomes a very real possibility. Of course the joint design, wall thickness and hydrogen contents of the weld deposit also play an important part. To give an example, the specification for C½ Mo, B.S. 1501-240 allows a carbon max. of 0.20% whilst B.S. 1501-620 restricts the 1%-Cr-Mo to 0.15% max. For this reason, one large international Oil Company places a carbon restriction of 0.14% max. on all C½-Mo steel it purchases. I.C.I. prefer not to do this because of the difficulty it brings in procurement although there was one stage on the Kanpur Fertilizer Project where we began to wish we had done so.

On this Project we had used C½-Mo quite widely to avoid the need for post weld heat treatment that 1% Cr-Mo requires. However, we ran into cracking of large weld neck pipe flanges. On investigation the carbon content of the cracked flanges was upto 0.34% which is well above the specified limit. Due to replacement difficulties it was necessary to use the existing materials and this was done by changing the welding spec. to a high pre-heat of 250°C and adding a post weld heat treatment of 640/660°C. A low hydrogen CO_2 welding technique was also employed. It would not have been possible to use low hydrogen metal arc-welding electrodes readily because of the difficulty of putting in a root run with low hydrogen electrodes. An alternative technique with slightly greater risk of cracking would be to use metal arc rutile coated electrodes and cap with with low hydrogen electrodes. With a wall thickness of about 3/8″ or more this can safely be done.

Similarly when welding heavy steam pipe work in 2½ Cr-Mo or 1% Cr-Mo it is the I.C.I.'s practice to put root runs in with carbon steel. This provides a more ductile root and there is less chance of the root cracking under restraint forces than when a matching root run is put in. Where the pipe thickness is of the order of 1″ or more the lower creep strength of the root run is easily tolerated and long service experience has also proved this practice to be completely safe.

Cracking of Carbon Steel

Cold cracking or hard zone cracking of the type first described for C½Mo steel can also occur in carbon steel especially in the higher carbon varieties at UTS strength levels of about 30/32 tsi UTS and section thickness of 1″. However this is easily prevented by preheat and the choice of the correct low hydrogen grade of welding consumable.

Another type of cracking which has caused quite a bit of trouble more recently among boiler plant users is the hot cracking of carbon steel particularly after oxy-acetylene welding. This emerged after the 27 tsi UTS grade of steel tubing began to be widely used for super-heater and steam generating tubes instead of the softer 23 tsi grade. In this instance the cracking is in the fusion line itself and frequently starts from the weld root. As it does not fully penetrate the wall thickness, it is not easily detectable until a failure occurs in service. Radiography, of course, does not pick up the cracks very readily. It is called hot cracking because the initial crack occurs during welding in a region which is still at high temperature i.e. about 1000°C compared with cold cracking at about 100/200°C.

Again, investigation by BWRA has disclosed the reason for the cracking. Cracking frequently occurs when the Mn/S ratio is less than 10 : 1 and it is never found if the ratio is greater than 40 : 1. The reason why there was less cracking with the 23 tsi grade steel was that it was more tolerant of a low Mn/S ratio due to its lower carbon content. The cracking is due to films of iron sulphide weakening the grain boundaries and when there is plenty of Mn present the sulphide is distributed as globular MnS within the grains and does not occur as films in the grain boundaries. Oxy-acetylene welding is much more likely to lead to cracking because of the greater heat input per unit volume of weld leading to a longer period in the dangerous temperature range.

The best advice to design engineers at present therefore is to avoid the use of 27 tsi steel in situations where gas welding is the only practicable method of fabrication e.g. for boiler tubes. If it is possible to be sure at the design stage that material with an adequate Mn/S ratio is available then this limitation need apply. However this is rarely the case especially in India and therefore it is prudent to use the lower strength when gas welding is to be done.

Stainless Steel/Carbon Steel Welds

The welding of two dissimilar materials is frequently necessary but it is often approached with such trepidation by the design engineer that he avoids the joint and uses a larger amount of expensive stainless steel than is necessary. Provided the correct procedure is used there is no difficulty at all in making a sound weld between stainless steel and carbon steel. On the other hand if the procedure is incorrect the weld can be most unreliable. The main point to remember in specifying a procedure is that carbon steel welding consumables should never be used if the fusion face of the joint includes stainless steel. Invariably a small amount of stainless steel will be fused into the cabon steel weld pool. The average alloy carbon then approximates to a ferritic low alloy steel. In other words the 18% chromium 8% nickel steel becomes a 1.8% Ni steel within the solidifying weld deposit. Inevitably, this will be brittle and probably it will crack as it is a type of low alloy steel which is not weldable without high levels of preheating.

When a stainless steel welding consumable is used there is dilution by the carbon steel side of the joint, and again assuming a 10% pick up the composition of the 18/8 deposit becomes 16.2% chromium and 7.2% nickel. This still gives an austenitic structure and no cracking difficulties should occur. Should the joint design be the type which leads to a high degree of dilution of the weld pool by the carbon steel parent material it would be advisable to use a 25% Cr, 20% Ni type of weld filler. For a more accurate analysis the composition of the weld and parent metal is often compared with the Schaeffer diagram which can be found in most text books in the welding of stainless steel (Fig. 2). However, this refinement is not often found to be helpful in practice as there are generally too many unknown factors involved. In general, the author would advise the use of 18/10/3, Cr/Ni/Mo for filler material with dissimilar joints of low to medium dilution. This gives a greater margin of safety against cracking than the plain 18/8 type of filler although for un-important joints the latter could be used.

On important joints where failure would be dangerous or even disastrous, the finished joint should be

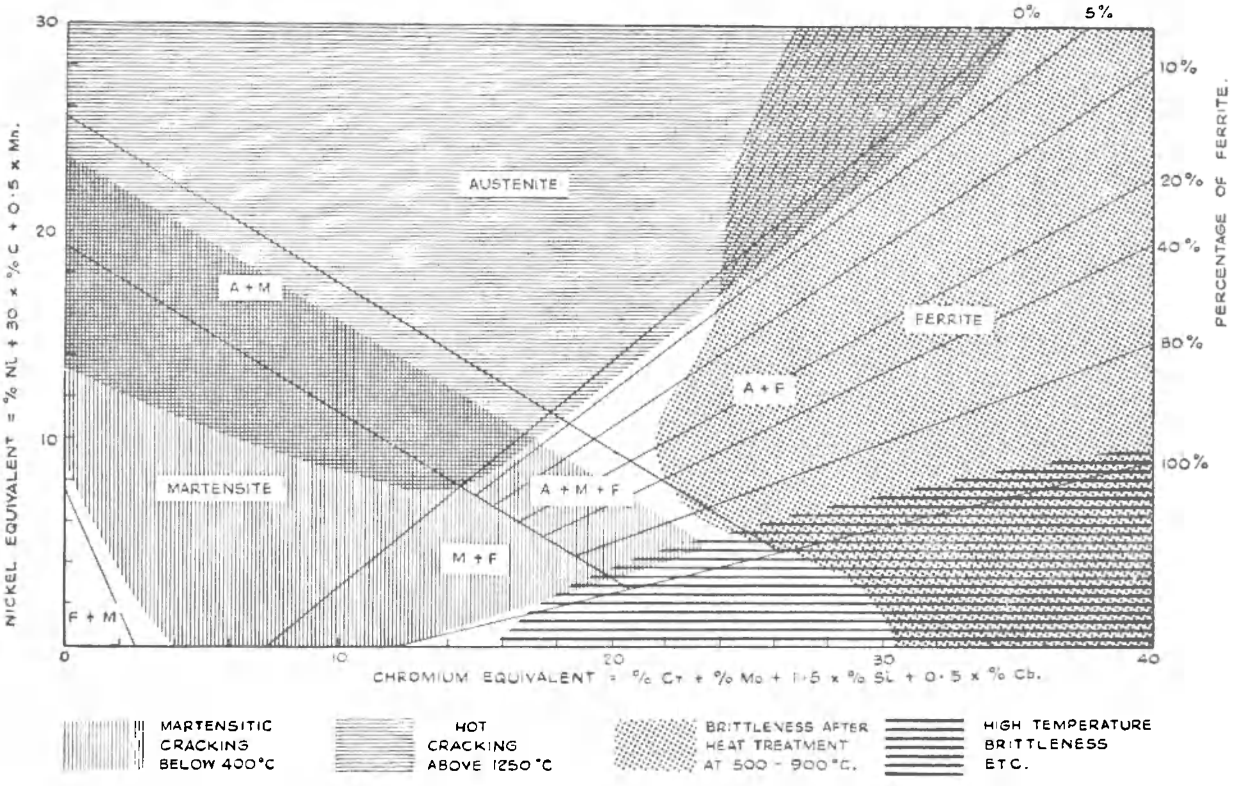

Fig. 2.

crack tested by dye penetrant. Where high temperatures are involved i.e. above about 350°C, more careful metallurgical consideration has to be given because of the possibility of carbon migration and embrittlement. At higher temperature, it is essential to use a high nickel weld deposit such as Inco-weld A (Ni-Cr-Fe ; 75-15-10) which provides a barrier against carbon migration and carbon and stainless steel. Satisfactory service up to 540°C has been obtained in H.P. steam service with this type of joint. Under thermal cycling conditions above 500°C particular care is necessary and the time spent at the peak temperature is a very important factor as it determines how much creep can occur on each cycle as a result of the thermal stress. I will not elaborate on this as the whole thing becomes a bit of a metallurgists' nightmare.

Repair of Failures

This is often a much more difficult job to do than making the original fabrication welds as positioned welding with limited access may be involved. The surfaces are generally contaminated and the weld preparation is far from ideal if it has to be prepared by hand grinding. A further hazard is that once material has been in service it may have become embrittled, especially so in high temperature service.

The most important thing to remember with repair welding is that the crack must be completely removed by chipping and/or grinding. Then the surface adjacent to the weld preparation must be cleaned up—again by grinding. Magnetic or dye detection should then be carried out to ensure that there are no cracks remaining adjacent to the weld preparation. Before reaching this stage it would be advisable to have had a general examination done to ensure that there are no other cracks of defective areas about to fail and, if other cracking is found, it would be time to call in a good metallurgist.

When embrittlement occurs in service, repair welding can be very difficult. With high temperature resisting steels such as 18/37 Cr-Ni and 25/20 Cr-Ni the material can become as brittle as cast iron and is even more difficult to repair weld. One technique which is used is to give the failed equipment a heat treatment at 1250°C. This is not easy to do unless it is simple in shape and even then very careful temperature control is essential, otherwise 'burning' of the steel will occur. On pipe and headers it has been done successfully in situ by I.C.I. The effect is to take the brittle chromium carbides which form an intergranular network back into solution. Fairly rapid cooling after the heat treatment is therefore desirable. Sometimes, in spite of the heat treatment, cracking occurs during welding where the joint is restrained e.g. a pipe fixed at both ends. If it is not possible to relax the restraint, a technique which has been found useful in I.C.I. is to cut out a length of the pipe—say 12″ and weld two separate 6″ pieces of new material to each end. The final closing weld which is under restraint is then made between new material. Experiments with a wide range of electrodes have shown that the type of electrode used makes little difference to success if the material is embrittled.

Sometimes embrittlement occurs in material which has not been put to high temperature in service. For example Titanium. A few years ago the author has had experience of trying to repair weld a titanium tubular heat exchanger. Frequent cracking of the tube/tube plate weld occurred and welding proved impossible and finally mechanical expansion methods had to be used. Subsequent examination where the equipment ws taken out of service showed that it had been embrittled by the formation of titanium hydride as a result of hydrogen produced by corrosion diffusing into the metal. This hydrogen embrittlement of titanium is now better understood and precautions are taken to ensure that it does not occur in service. If repair welding of titanium were now to be required, the possibility of embrittlement would be borne in mind and the repair technique modified accordingly.

With an unusual material it is difficult to know whether cracking which occurs during repair welding is due to lack of ductility in the material or due to fine cracks in the material which are being opened up by the welding stresses. For this reason it is essential to carry out crack detection prior to repair welding and should any difficulties be encountered a full metallurgical examination of material cut out from the defective area will probably be essential. With any failure, unless the cause is obvious and further failures cannot be tolerated, it is desirable to have a metallurgical examination before the original failure is disturbed.

Hard Facing of Stainless Steel

A final example may be of interest in that it illustrates the difficulty in distinguishing between mechanical failure and corrosion failure upon superficial evidence. The object was an austenitic stainless steel valve on which the seat was faced with stellite (a 60-30-8 Cobalt—Chromium—Tungsten alloy) to prevent wear. Coupon corrosion tests had shown that the stellite would stand upto the service conditions just as well as the stainless steel. However, after a few weeks in service the valve was found to be leaking and when opened up the ring of stellite literally fell off the seat. On the other seat, the stellite was cracked around the interface of the deposit and the steel body. It was thought that welding stresses combined with the low ductility of the stellite deposit had led to the cracking.

Metallurgical investigation told a different story however. The stainless steel adjacent to the high carbon stellite deposit had been heavily carburised and although it was a stabilised grade of steel. the high carbon zone had suffered severe intergranular corrosion attack. The zone was only about 0.010″ to 0.020″ wide and corrosion had proceeded along the grain boundaries within this zone with great rapidity.

If the welding procedure had been oxy-acetylene, the failure would probably have occurred even more rapidly because the carburisation effect is worse than with the TIG technique which in fact had been used.

The remedy in this case was to give a 1050°C heat treatment followed by rapid cooling. This ensures that the carbide in the carburized zone is kept in solution and does not segregate to the grain boundaries making the steel susceptible to intergranular corrosion. Often heat treatment is not practicable, and if not, it has been found that the application of a run of stainless steel weld metal along the stellite steel fusion line is an effective alternative. The carbon picked up from the stellite into the molten stainless steel weld pool is distributed uniformly instead of being concentrated in a narrow zone. This reduces the tendency to form grain boundary carbides and therefore there is much less danger of severe local attack. TIG welding should be the first choice for hard facing stainless steels. Metal arc may be used if it is all that is available but oxy-acetylene never !

Incidentally, quite light corrosion will cause rapid intergranular corrosion attack if the zone is susceptible enough and just because the part is not going to be immersed in strong acid and is only handling orange juice does not make it safe.