Combined Cycles for Stress Relieving of different Equipment

K. BHASKARA RAO
D. S. P. RAO*

Combined cycles for stress relieving of different equipment are inevitable in a pressure vessel industry, since the furnaces are generally too big to accommodate only a few similar vessels and stress relieving is too often required beyond the mandatory requirements of the code. Before proposing a combined cycle one must have a thorough knowledge about the materials, which go for the heat treatment. It is better, if the materials and welding are subjected to simulated heat treatment and tested to assess the influence of proposed heat treatment. Two such experiments, which have been conducted here to evolve the deterioration in mechanical properties on prolonged stress relieving are given in this paper and the data is analysed.

The essential considerations to be taken before implementing a combined cycle are :

1. composition of the base materials.

2. weld deposit analysis and the possible complex structures in case of overlays and dissimilar joints.

3. whether or not preheating is done.

4. deterioration of mechanical properties like yield strength, ultimate tensile strength or ductility and impact value with prolonged stress relief.

5. important welding parameters like heat input and nature of flux etc. to assess the dilution from the parent metal.

6. the effect on thinner sections of the vessels, like nozzles, flange, etc.

7. the creep, sagging and other distortions which result due to increased exposure to higher temperatures.

The materials which are generally used for fabrication of pressure vessels are broadly divided into four categories.

1. Plain carbon steels,
2. Low alloy steels,
3. High alloy steels, and
4. Clad steels.

The stress relieving of high alloy steels is different from the remaining three types, and as regards clad materials much consideration is given to the base material, although possible precautions are taken to see that the clad properties are not impaired. Even the remaining two types namely carbon steels and low alloy steels require stress relieving at different temperatures to achieve better mechanical properties, although various codes suggest the same minimum temperatures. Certain codes even facilitate employing lower temperatures with increased soaking periods to a limited extent, but these increased soakings may

* Messrs. K. Bhaskara Rao and D. S. P. Rao are with Bharat Heavy Plate & Vessels Ltd. Visakhapatnam.

result in deterioration of mechanical properties. However, every combined cycle is a compromise to a certain extent, sacrificing a bit on one plane to gain on the other and hence, it is all the more important to know the precise behaviours of materials involved.

We hereunder give an account of two investigations regarding the deterioration of mechanical properties of :

1. a dissimilar joint,

and 2. welded plates and parent metal of different thicknesses.

I. A dissimilar joint of SA 240 : 321 and SA—387 Gr. B materials with 309 Mo electrode has been taken and subjected to various durations of stress relieving at different temperatures and was subjected to bending tests. The specimen that was subjected to stress relieving at 700°C for 2 hours failed in the tests without taking any bending, with a sudden and violent fracture, whereas the specimen heat treated at 600°C for one hour withstood the 180° bending. The micro structures of the above joints revealed the secondary massive precipitation of carbides in the first specimen and lesser amount in the second specimen. The explanation for the brittle fracture is that the precipitated carbides must be acting as stress raisers because of the differential resistance to transmission of stresses in the specimen. The elongation and ability for stretch is very much less in the carbides, when compared to either austenite or ferrite, which makes the carbide region as a stress concentrated region. The above carbide precipitation in the ferrite and the consequent embrittlement are the functions of time and temperature and can be regulated by adopting lower temperatures and lesser duration of stress relieving. But it cannot be construed, that the above particular joint will always pass the bend test, if it is heat treated at 600°C for one hour or it will always fail, if it is heat treated at 700°C for two hours. They hold good only for the parameters used in the welding of the above joint. If the parameters of the welding are changed, the suitable amends to the subsequent heat treatment also must be followed. Unless an extensive experimentation is done, it is not possible to know, how a small change in any one of the parameters is going to influence the joint, and what remedial measures are to be taken.

We may come to certain conclusions of how to tackle the heat treatment of a dissimilar joint, basing on the above experience.

1. Regarding the dissimilar joints similar to the above, the welding parameters and the stress relieving temperatures and durations may be varied in order to find out the safe limitations.

2. The barrier layer to limit the carbon transport into the weld deposit also may be tried, which most probably gives more freedom in the subsequent welding and stress relieving.

3. Different types of electrodes also may be tried without sacrificing any of the advantages of the two different metals in the joint. A higher austenitic electrode may hold the key to this particular problem.

II. To determine the deterioration in mechanical properties of welded plates and parent metal, three weld plates of 100 mm & 70 mm of SA 515 G. 70 and 14 mm of SB 42 and a parent metal of SA 515 Gr. 70-36 mm. thk. are taken and subjected to different durations of stress relieving, at 610°C ± 10°. Test blocks of 100 × 100 mm, 70 mm × 70 mm, 14 mm × 25 mm and 36 mm × 50 mm cross section are cut from the above plates and subjected to stress relieving for various durations from one hour to 20 hrs, and tested for tensile strength. The mechanical properties under different conditions, are tabulated below along with the specification values of each material :

MATERIAL :

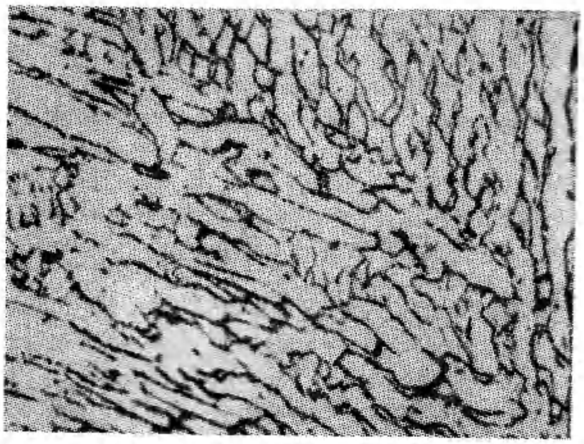
SA 515 Gr 70-100 mm tk. WELDED PLATE

Mech. properties	As received	Stress relieved for 5 hrs	10 hrs	15 hrs	20 hrs	Specification Values.
Yield Strength (kg/mm^2)	34.5	37.6	35.20	34.05	33.74	26.7 (Min)
Ultimate tensile strength (kg/mm^2)	56.0	56.88	54.40	52.80	52.42	49.2 to 59.76

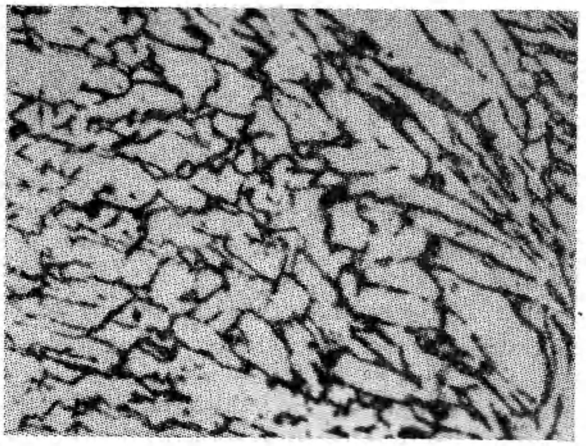
MATERIAL :

SA 515 Gr 70-70 mm tk. WELDED PLATE

Mech. properties	As received	Stress relieved for 3 hrs	6 hrs	9 hrs	12 hrs	20 hrs	Specification Values
Yield strength (kg/mm^2)	33.75	35.92	33.36	31.59	30.83	29.88	26.7 (Min)
Ultimate tensile strength (kg/mm^2)	55.90	55.39	54.42	53.21	50.47	49.88	49.2 to 59.76



1. Structure in the weld in as welded condition.
Magnification × 1260



2. Structure in the weld after stress relieving at 600°C for one hour. *Magnification × 1260*

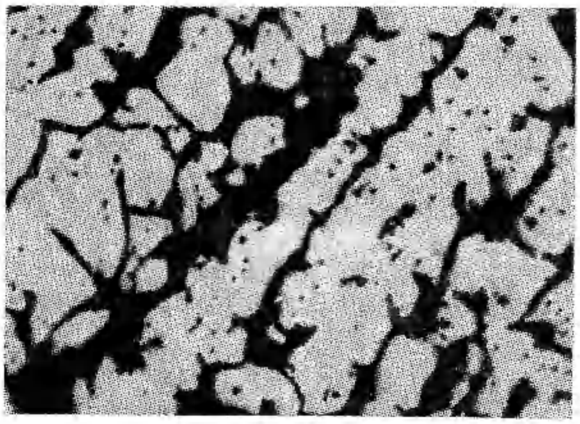
MATERIAL :

SB 42-14 mm. THICK WELDED PLATE

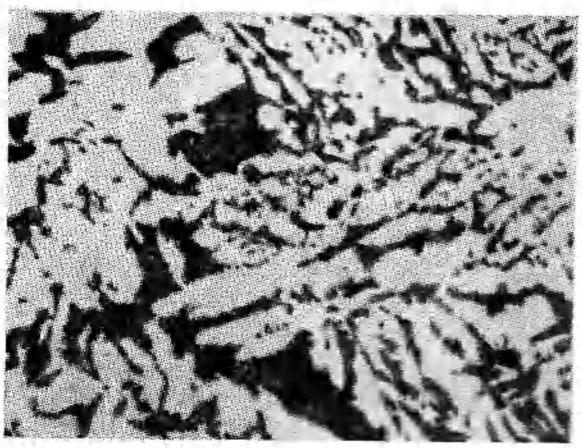
Mech. properties	As received	welded	Stress relieved for 1 hr	2 hrs	4 hrs	10 hrs	Speci-fication Values
Yield strength (kg/mm²)	31.10	40.58	58.57	39.41	38.56	34.3	23.0
Ultimate tensile strength (kg/mm²)	51.0	54.18	50.83	50.26	50 03	48.12	42.0 to 50.0

Before going into the discussion of the test results, it may be noted that the fall in mechanical values may not be same for all steels. Factors other than the heat treatment like impurities, and their pattern of scatter, atomic dislocations etc. also effect the fracture and influence the strength. These plates under test are welded plates and the fracture occurred in the parent metal in all the cases. Hence, the mechanical values represent parent metal properties influenced by welding stresses.

The test results tabulated above show that the tensile and yield strengths progressively fall as the duration of stress relieving increases. In case of 515 Gr 70, tensile and yield strengths fall by 1.0 to 2.0 Kg/mm² when the soaking time is doubled and by about 4.0 to 5.0 kg/mm² when it is increased four times. The rate of fall is progressively decreasing, difference being 1 to 2 kg in the first lap and 0.5 to 0.6 kg in the last. In case of weld plates, the yield strength and ultimate tensile strength in as welded condition are much higher than in the as received condition. In case of SB 42, normal duration of stress relieving for this thickness is about 35 minutes. After one hour of stress relieving for this thickness the Ultimate Tensile Strength has come to the level of



3. Structure in the weld after double stress relieving, at 703°C for two hours each time.
Magnification × 1260



4. Structure in the weld stress relieved at 700°C for ten hours. *Magnification × 1260* original plate in as received condition but not the yield strength. There is no further drop when this is stress relieved for four hours. However, after 10 hours of stress relieving, there is a steep decline in the values. They dropped by more than 6 kg/mm^2.

Although in this specific case, the mechanical values of prolonged stress relieving are well above the minimum specified values by virtue of their higher strength in as received condition, we must be concerned with the drop in their values. The drop in the parent metal need not be necessarily equal to the drop in the welded specimen, which is influenced by the heat input while welding. Hence, a parent metal with marginal mechanical properties has been taken and subjected for stress relieving for different durations. The drop in the ultimate tensile strength is only 2 kgs / mm^2 after 20 hours of stress relieving but a situation may arise, where it may not be possible to sacrifice any strength, and it may also be necessary to have a prolonged stress relief. In such case, the problem may have to be tackled by providing slightly higher thickness to compensate the loss in U. T. S.

If we analyse the above data, we find that the yield strength of the specimen after stress relieving for specified duration is more than the yield strength of the plate in as received condition. This suggests that the residual stresses due to contractional forces of welding are not completely relieved. It may also be noted that the yield stress has been much influenced by welding and not the U. T. S. The residual stresses are the internal stresses in a body, which can exist in the absence of any external pressure or loading and be balanced by having tensile residual stress at one place and residual compression stress at another place.

In welding, the metal is subjected to expansion and contraction due to local heating and cooling in addition to the shrinkage of weld deposit. The shrinkage of weld deposit is in all directions upto 4% of its volume. While the weld metal cools from fusion temperature, it tries to shrink, but is restrained by the parent metal surrounding it. This shrinkage has got to be accommodated by plastic straining of the weld metal and the resulting residual stress level, which is associated with the plastic strain must be slightly above the yield point of the material.

The strength of the weld deserves consideration for the purpose of combined cycles. A weld can be designed to have any amount of tensile strength within the range of parent metal strength or upto 15% higher than that as per certain codes. Supposing the weld metal is designed for acceptable lower strengths for want of other advantages, it stipulates a limit for combined cycle. But one advantageous factor is that the deterioration of weld strength on prolonged stress relieving is very low when compared to parent metal. If these low tensile welds are made especially on thinner sections of the vessel, the relaxation for the combined cycle becomes much more difficult.

Normally the soaking period for stress relieving is prescribed basing on the shell/head thickness, although certain parts of the equipment like nozzles and flanges are thinner by half to one third thickness. While proposing the combined cycle, one must take into account the deterioration that would be caused especially to the thinner sections. It may also be noted that generally the tensile strength of the thinner section is slighly higher than the tensile strength of the thicker sections due to higher mechanical working and scatter of impurities.

The creep and sagging may take place while the vessel is stress relieved. Creep is the time dependent deformation of materials, which occurs under constant stress and temperature. The weight of the vessel acts as stress and at elevated temperatures of stress relieving. the effect of creep will be considerable, when the exposure times are too long. Hence, this factor must be considered as otherwise there is a danger of physical deformation beyond the acceptance limits. While considering the combined cycles, it must be known whether preheating before welding has been done or not. The preheated welds require lesser stress relieving time since the rate of cooling after welding is slow and the residual stresses due to shrinkage against restraint and phase transformation are low and probably distributed in the wider area.

From the above investigation the following observations we may draw :

1. As regards the weld plates, it may be seen that the yield strength is much influenced in welding rather than U.T.S.

2. Even with prolonged stress relieving, yield strength is not falling below the value in as received condition, but U. T. S. of the welded specimen as well as parent metal are falling much below.

3. The contractional stresses contributed by welding are only partially relieved in the normal heat treatments.

4. Since our designs are based on U. T. S. we have to draw a limit for duration of stress relieving, or increase the thickness of the sections, to compensate the loss of strength, if prolonged stress relieving is inevitable.

Conclusions

The codes give a general rule that the minimum stress relieving duration is one hour per one inch thickness and vessels of different thicknesses may be stress relieved in the same furnace charge, as per the requirements of the thickest vessel. They are silent about the maximum and minimum limits of the thickness that can be stress relieved in the same furnace charge. On a reference, the A S M E code interpretation committee clarified that there are no maximum and minimum limits that can be stress relieved in the same furnace charge. They however, advise that the drop in tensile values should be taken into account, while recommending durations for the heat treatments.

In the case of equipments involving weld joints of dissimilar metals like high alloy steels, to low alloy and carbon steels, where electrodes like 309 Mo type having higher ferrite content are used, the temperatures and holding periods are not specified in the codes nor can the established temperatures like 680—720°C for Co-Mo, Cr-Mo-V steels be followed without proper experimentation. If the stress relieving parameters proved sound for dissimilar welds cannot effectively relieve the stresses of the other joints in the equipment, the solution appears to be choosing an alternate electrode for welding, which will not pose any problem or local stress relieving of that particular joint.

As such, in the case of weld joints of dissimilar metals, weld metal properties also have to be taken into consideration, in addition to the parent metal properties, while deciding the stress relieving parameters. However, the procedure test specimen have to be stress relieved under simulated conditions of the vessel before they are subjected to mechanical tests. If the procedure test specimen is selected in such a way that it represents the most unfavourable conditions of heat treatment, we would be able to know how much laxity is left with us. A compromise to a certain extent can always be struck provided one is in the knowledge of properties and the behaviour of materials he is dealing in.