DISCUSSION

A. W. PENSE[2]

This paper by Dr. Meitzner represents a good summary of the current literature on stress relief cracking. It is an up-to-date evaluation of what influences a phenomenon which has received more attention in the last year or so because of renewed evidences of cracking in alloys not previously thought to be susceptible.

Work just completed at Lehigh University on three steels, two of which were not included in Dr. Meitzner's work, have indicated that the equation of the Japanese (%Cr + 3.%Mo + 8.1%V − 2) is not always accurate when dealing with some of the pressure vessel steels currently being welded. For example A543 steel, which by the Japanese equation should be sensitive to cracking in the LeHigh restraint test, did not show such cracking; whereas A533A steel which, according to the Japanese, ought not to crack, did show mild cracking under severe restraint conditions. These results indicate that there are other factors which influence cracking and that some of these factors, which have been mentioned by Dr. Meitzner, are apparently overriding in certain cases.

For example, Dr. Meitzner suggests that the use of low strength weld metal may reduce the incidence of cracking; indeed in tests we have run, high strength weld metals increased cracking tendency and low strength weld metals decreased it. For some steels, for example A517F, the use of low strength weld metal in conjunction with high strength base plate reduced cracking to a minimum amount whereas the opposite combination of high strength weld metal and lower strength base plate produced 100 percent cracking in Lehigh restraint specimens. In A533A steel, low strength weld metal also reduced cracking tendency. In the instance of weld procedures, it has been found that the use of preheat, as mentioned by Dr. Meitzner, will effectively reduce cracking in steels; as will the use of higher heat input. Thus it appears that more experimental work along these lines may indeed be advisable if cracking in sensitive steels is to be reduced. It must be pointed out, however, that in extremely sensitive steels even the use of preheat, higher heat input, and low strength weld metal did not completely eliminate cracking.

R. A. Swift[3]

I would like to congratulate Dr. Meitzner on a fine job. He has added further evidence to the theory that this phenomenon occurs as a result of composition of the weld deposit and plate and not solely to the welding parameters and stress relieving cycle.

The experimental techniques used to study the mechanism of cracking are especially noteworthy. The manner in which Dr. Meitzner correlated stress relaxation tests, notch sensitivity of base plate and creep ductility with susceptibility to stress relief cracking, is interesting. Usually only one such test is used and the reader is left with the feeling that a variety of tests could be incorporated. This would help to find a quick test to evaluate the susceptibility to stress relief cracking. Dr. Meitzner has done just this. There is little doubt in the reader's mind that these phenomena are related and that several short term tests can be used instead of a lengthy welding study.

Another interesting aspect is the discussion of temper embrittlement. Dr. Meitzner has indicated that in the steels used in his study, separate mechanisms operate to cause stress relief cracking and temper embrittlement. Recent work on 2$^1/_4$Cr-Mo Steel (Bruscato, Welding Research Supplement, April 1970) indicates that the phenomena of temper embrittlement and creep embrittlement may be related. This is as of yet an unresolved point of discussion. The fact that stress relief cracking in A517F and A517J does not correlate with temper embrittlement susceptibility attests to the need of more research in this area.

One point that I feel may be clarified is the effect of heating rate to the stress relieving temperature on the susceptibility to crack. We have collected data that shows the temperature at which cracking occurs increases with increasing heating rate (Swift, R. A., Welding Research Supplement, May 1971). From the appearances of the data, the heating rates studied are on the top side of a "C" curve. The low heating rates used in the stress relieving of heavy walled pressure vessels may be beneficial rather than detrimental. Has Dr. Meitzner evaluated this aspect of the stress relieving cycle?

Once again, I would like to congratulate Dr. Meitzner on a fine job. He has undoubtedly helped clear up some of the controversy surrounding stress relief cracking.

Author's Closure

The discussion comments by Dr. Pense and Mr. Swift are appreciated by the author. The Lehigh experiments cited by Dr. Pense provide further verification that the tendency for stress-relief cracking can be minimized in certain cases by careful selection of welding electrode, preheat, and welding conditions.

Mr. Swift has raised the question of heating rate to the stress-relieving temperature. The rate used in most of our restraint tests was nominally 50 deg F/min, but several A517F and A517J tests were also run at heating rates of 10 deg F/min to 1100 deg F for comparative purposes. Similar results were obtained in both cases, i.e., the slower heating rate did not significantly alter the cracking results.

Further discussion of the effect of heating rate in crack-sensitive ferritic steels is included in reference [13] (Bentley) of this paper. On the basis of hardness tests and metallographic work, Bentley concludes that "...heating up to the stress-relieving temperature at slow rates which permit the precipitation reaction to occur at lower temperatures is also likely to incur greater embrittlement." Therefore, there is some evidence that slower heating rates may be detrimental. Further studies of this question would certainly be desirable.

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