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1. HOW IS THE IDEAL PRESSURE FOR PRODUCTION USE DETERMINED?

The ideal expanding pressure is theoretically determined first from equations and tables based upon the curve published in "Hydroexpanding: The Current State of the Art" presented at the Joint Power Generation Conference in October 1982. The curve was adapted from, Goodier, J.N. & Schoessow, G.J., "The Holding Power and Hydraulic Tightness of Expanded Tube Joints: Analysis of the Stress and Deformation", Trans. ASME July 1943.

It provides the theoretically highest expanding pressure that will: (1) not exceed the plastic limit of the tube at its inside; and (2) will not cause the pressure of the tube on hole to exceed the plastic limit of the tubesheet hole. In the Goodier & Schoessow work, it was demonstrated that the highest expanding pressure that met these conditions would produce the maximum interfacial fit pressure. It was also demonstrated that this was the pressure that would produce the highest residual interfacial pressure when expanding pressure was released.

It is extremely important to note that the expanding pressure chosen from the chart must be related to the actual mill test values of tube and tubesheet yield shown on mill test reports. Specifically, it should be pointed out that there may be a wide variation in tube yields from heat to heat, and the minimum values shown in the ASME Code cannot be used for setting expanding pressures. Suggest that they maintain a tube map showing where tubes from each heat are located.

Empirical determination through tests and the use of coupons covers items not considered in the theoretical approach:

1. Tube spring back varies with different tube material. Titanium is the worst, showing about .004" spring back or relaxation when pressure is released. This degree of spring back is not available in the published data on material properties such as tensile, yield, elongation, modulus, etc. It must be considered that hydraulic expanding, unlike roller expanding, DOES NOT mechanically work harden the tube; therefore, the tube should be deflected sufficiently to overcome spring back. Work hardening does tend to overcome spring back. The various deleterious effects of this are well known in the industry.

2. Effect of grooves upon sealing and pull strength is best determined by coupon tests.

3. Effect of variations in surface conditions of tube O.D. and tubesheet hole cannot be calculated and one needs to resort to empirical findings.

   Report HAR114, Appendix, shows a typical test program on a particular tube and tubesheet combination. Through a test such as this, the following can be determined:

   a) Tube O.D. change vs. pressure, including spring back characteristics.

   b) O.D. change of tube and coupon or portion of tubesheet, which determines pressure, needed to overcome tube spring back characteristics.

   c) Groove width and depth effect on penetration of tube and ability to cut through tube O.D. surface discontinuities. It also shows amount of shear shoulder which produces pull strength. This data is evaluated against a) and b) and the optimum groove configuration determined.

2. WHAT IS THE PERMISSIBLE VARIATION FROM SWAGE PRESSURE (+ or -)?

Swage pressure should be held as close as possible. With HydroSwage, a +/- of 1000 psi is easily held. The controller set points and indicating lights give the operator control of the swaging process. This is in stark contrast to the lack of control with roller expansion, which is dependent upon operator "feel" and skill. Furthermore, the HydroSwage performance can be accurately measured and recorded.

It should be noted, that the variation from set pressure on the HydroSwage system is well within the limits of precision of data on the tube and tubesheet properties.

3. WHAT ARE THE EFFECTS OF EXCEEDING THE SWAGE PRESSURE RANGE?

The effects of exceeding the maximum theoretical pressure are to initiate tube or tubesheet extrusion. The actual degree can be determined by calculation or review of test data. It can also reduce leakage and increase joint strength. This is in contrast to roller expansion, where over rolling will break the bond between tube and tubesheet, increase leakage, and reduce joint strength.

An under pressure condition will reduce joint strength and increase the tendency to leak. This can be corrected by reswaging at a higher pressure.

4. FOR WHAT TIME PERIOD IS THE PRESSURE HELD?

There are two adjustable time periods:

a) Prefill Time. This is the time to fill the tube at low pressure and is determined by the diameter and length of tube being pressurized. Time can be determined by observing the time it takes for the pressure to stabilize.

b) Swage Time. This is the swage pressure holding time. This time can be determined by observing the pressure read-out. It can also be observed more scientifically by attaching a strip chart recorder and observing the profile of the pressure trace.

5. WHAT IS THE INTERFACIAL PRESSURE BETWEEN TUBE AND TUBESHEET WITH SWAGE PRESSURE APPLIED

No attempt is made to idealize interfacial pressure during application of expanding pressure. Based upon the Goodier & Schoessow work, maximum expanding pressure is applied that will not cause extrusion of tube or tubesheet. This will provide the highest residual interfacial fit pressure when the expanding pressure is withdrawn.

The original Goodier & Schoessow paper, can be used to determine the stress state of the tube-tubesheet structure under various pressure load conditions. Podhorsky & Krips papers provide a theoretical consideration which gives results somewhat different from the Goodier & Schoessow investigation, Uragami, K. Sugino, M. Urushibatat, S. Kodama, and Fujiwara's, "Experimental Residual Stress Analysis of Tube to Tube Sheet Joints During Expansion", ASME paper 82PV-61, give other results.

Since the interfacial pressure during application of pressure is not idealized, permissible variations have not been established. The variation in interfacial fit pressure during application of expanding pressure will essentially vary linearly with the limits of variation of the HydroSwage set pressure which is + or - 500 psi. There is no way directly to measure the variations in interfacial pressure during or after expanding.

If the expanding pressure is exceeded, it may cause either the tube or the tube hole to extrude.

If the tubesheet extrudes, it will distort. When this happens, joint strength declines.

6. WHAT IS THE RESIDUAL INTERFACIAL FIT PRESSURE REMAINING AFTER SWAGE PRESSURE IS REMOVED

Theoretical calculations for residual pressure can be made by using the Soler-Xu Hong work, embodied in chapter 7 of Soler, A.I. and Singh; K.P., "Mechanical Design of Heat Exchangers and Pressure Vessels", Arcturus Publishers, Inc., Cherry Hill, NJ, 1984. This work provides in Appendix 7.D, the computer code for calculating residual fit pressure among other things.

However, the theoretical calculations notwithstanding. Relying on theoretical joint strength calculations using any expanding method is not recommended. Instead, test models should be made and pullout results should be correlated with expanding pressure.

Consider this --- the interfacial pressure is but one of three major factors in determining joint strength and tightness. The other factors are surface area in contact and effective coefficient of friction. You can make an approximate calculation of area in contact, but unless you can control both tube surface and hole surface within narrow limits, you cannot truly predict the coefficient of friction that exists in any tube-tubesheet assembly. In addition, the coefficient of friction will vary from hole to hole depending upon the variations in machining.

When the idealized residual pressure is exceeded, the joint strength declines. This relationship is illustrated in the work by Goodier and Schoessow.

7. DIAMETRICAL CLEARANCE BETWEEN TUBE AND TUBESHEET?

Ideally, there would be no clearance between the tube and tubesheet hole when expanding pressure is applied. As a general rule, the smaller the clearance, the better from the expanding point of view no matter what expanding method is used. What establishes the clearance used by manufacturers is their ability to stuff the tubes through the tubesheets and baffles. This varies with the size of the structure, its configuration and the tube diameter.

From a practical standpoint, the best quality will be obtained by using the TEMA Special Close Fit drilling tolerances and adhering to tubing manufactured in complete conformity with Section II of the ASME code.

8. WHAT IS EFFECT OF TUBESHEET SURFACE PROFILE AND GROOVES?

Circumferential markings are beneficial and will indent themselves into the tube O.D. surface. This will increase joint strength and reduce leakage. Longitudinal marking form leak paths and increase leakage. It is therefore, recommended that the tubesheet holes be drilled only with no reaming afterward.

Grooves are recommended and serve to interrupt longitudinal markings, thus providing a seal. Various investigators have examined the effects of grooves on strength and tightness, both for roller expanded and hydraulically expanded tube configurations. Specifically joint strength increases linearly with groove depth. The minimum effective groove depth for hydraulic expansion was shown by Yoshitomi, and others, "Tube-Hole Structure for Expanded Tube-to-Tubesheet Joints", U.S. Patent No. 4,142,581, to be about 1/64".

Generally groove dimensions are approximately 2 1/2 times wall thickness in width with a depth of approximately 20% times wall thickness. Final dimensional determination can be further optimized by test.

Out of round and tapered holes are easily handled as pressure is equal in all directions and the tube will form itself to the I.D. of the hole.

9. EFFECT OF RESPECTIVE PHYSICAL PROPERTIES OF TUBE AND TUBESHEET?

Generally speaking, the tubesheet should be stronger than the tube. With hydraulic expansion, the tube is deformed until it contacts the tubesheet. The tubesheet is then deflected within its elastic range sufficiently so that, when expanding pressure is released, the tubesheet relaxes and creates an interference fit with the tube O.D.

Specifically: It is always preferable to have the tubesheet yield strength higher than the tube yield strength.

It is always preferable to have the tubesheet modulus of elasticity lower than the tube modulus so that the tube hole will spring back more than the tube.

It is always preferable to have a harder hole than tube. According to the Goodier & Schoessow analysis, "no joint can be made if the tube is much harder than the plate, unless the tube is sufficiently thick".

If the tubesheet yield is less than 60% of the tube yield, it is problematical whether you can get a satisfactory expanded joint, no matter how you expand it. If the tube modulus of elasticity is very low and the tube yield stress very high compared with relatively high tubesheet elastic modulus and low tubesheet yield stress, satisfactorily tight, a strong expanded joint made by any process will be difficult to achieve and may not be achieved. This is especially true when the ratio of tube diameter to wall is greater than 20 (thin walled tubes).

10. WHAT ARE LIMITATIONS OF LIGAMENT AND TUBE WALL THICKNESSES?

The relationship between tube wall and ligament thickness is a design consideration. There are an infinite number of combinations. Each combination requires its own evaluation and no general answer is available.

Wall thickness by itself doesn't determine its swagability. The relationship between wall thickness and tube O.D., along with its tensile strength, determines how much pressure a tube will withstand. Therefore, since hydroexpanding does not apply force cyclically but only by uniformly applied pressure, any tube-ligament configuration that can be successfully rolled should be more capable of being successfully hydroexpanded. Generally, it has been found that HydroSwage pressure is approximately 2 1/2 times the calculated tube burst pressure.

Variations in wall thickness do not limit the effectiveness of HydroSwage.

The position of the tube hole relative to the center edge or corner of the tubesheet doesn't limit the effectiveness of HydroSwage. It may, however, affect the deflection characteristics of the ligaments.

11. WHAT IS CORRECTIVE ACTION FOR JOINT LEAK AND LIMITATIONS ON SWAGE PRESSURE?

Any Joint can be reswaged at the same or a higher pressure. In some cases, a short tack roll can be added if kept well inside the tubesheet. This would utilize the tighter fit produced by the roller work hardening without it extending into the transition zone.

The HydroSwage system is set at the factory for a maximum swage pressure of 60,000 psi. This can be increased, but it is not generally recommended.

12. CAN HYDROSWAGE MEET MILITARY SPEC REQUIREMENT OF A PULL OUT STRENGTH EQUAL TO TUBE YIELD STRENGTH?

This can be accomplished with use of properly designed grooves. The joint strength is determined by the shearing strength of the expanded portion of the tube within the groove.

13. WHAT IS FUNCTION AND SPEED OF THE TUBE LOC™ TOOL?

The tube lock tool serves to position the tube relative to tubesheet face. It also opens the diameter of the tube and makes it easier to insert the mandrel o'rings into the tube. The normal time to position the tube and lock it is 3 to 5 seconds.

14. WHAT ARE SPECIAL CONSIDERATIONS WHEN USING MANDRELS?

Mandrels come in 1/2 mm increments. o'rings, to be effective, must have squeeze within the tube I.D. The amount of squeeze is carefully worked out within the 1/2 increment sizing.

Tube ends should be chamfered on the I.D. to permit easy o'ring insertion.

O'ring seal life is usually determined by condition of tube entrance. It is not unusual to get 200 to 500 or more swages per o'ring.

The o'ring doesn't function alone. It is supported by a polyurethane backup ring, which is in turn supported by a six piece steel segment. These are designed to support pressures up to 60,000 psi.

There is scant likelihood of a tube rupture as long as the pressure zone is within the tubesheet.

Normal production rate is determined by dwell times and speed of operator inserting and removing tooling.

15. WHAT ARE THE PREPARATIONS FOR HYDROSWAGING?

Measure and mike tube I.D.'s for proper mandrel selection. (Refer to mandrel sizing chart in tooling handbook).

Make sure tubes are clean and I.D. of tubes are properly chamfered for easy insertion of mandrel and tube lock.

Measure and mike I.D. of tubesheet hole for accurate expansion zone. Also be alert for exact depth of chamfer in tubesheet hole, if applicable. Example: T/S hole thickness is 7/8". Expansion zone is normally 3/4" (1/8" & 1/8"). If there is a chamfer off 1/32", that makes the placement of the mandrel inside the tubesheet necessary to be a 1/32" more inside. The danger, if not done, is blown segments and o'rings.

Always check swage pressure for desired job. Please refer to pressure setting chart and please feel free to contact Haskel International for confirmation of recommended pressure settings as well as time settings.

If you have sized the mandrel for said tube and tubesheet job and after mandrel insertion you find that you can't achieve a seal, go to the next largest o'ring size.

Always use a liberal amount of lubricant with both the tube lock tool as well as the swaging mandrel. Recommended lubricant: Hydrolube Haskel P/N CN002082

Always refer to operating Manual on HydroSwage before starting a job and always feel free to contact Haskel International or your local Representative for advice.

16. TUBE EXPANSION BEFORE WELDING

Welding after HydroSwage may leave difficulties with the out flow of weld gases. There are numerous reports and studies that indicate the negative effects of welding gases that were not allowed to escape. For this reason, we recommend the use of a tube lock tool to position and lock the tube prior to welding. This process allows the welding gases to escape.

17. TUBE EXPANSION AFTER WELDING

Weld roll-over can effect the entry of the mandrel into the tube. The shop personnel should be instructed to run a cleaning reamer into the tube.

After welding, the welded surfaces should be fluid penetrant examined. When all welds are shown to be joint tested by an air-bubble test; depending upon how critical the welded joint is, a halogen or a helium leak test may be considered. Only after the weld is shown to be tight should you expand. After expanding the standard hydrostatic test is used to verify that the structure can withstand the stresses imposed by applying pressure of 1.5 X the maximum allowable pressure shown on the nameplate, corrected for temperature.

If the expanded zone started about 3/8" into the tube interior behind the weld, the expansion would not effect the weld at all, except to protect it from the effects of tube vibration. If expansion were to start right at the welded region, the weld would be stressed uniformly and have a slight tendency to work the weld. However, it is doubted that enough force would be applied to achieve the benefit of changing its character from a cast structure to a forged grain structure.

18. WHAT IS EFFECT OF WELD BEAD?

The weld bead affects the size of mandrel that can be inserted into the tube. A limited size weld bead can be sealed by the o'ring. Usually, the tube is drawn after welding, in which case there is no weld bead and thus no effect from it.

Expanded joints can be tested by any means previously used by the manufacturer. Leak test fixtures are available for leak testing individual tube stubs.

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