# THE USE OF EXPLOSIVE FORMING FOR FASTENING AND JOINING STRUCTURAL AND PRESSURE COMPONENTS

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ABSTRACT

Explosive expansion of tubes into tubesheets has been used for over 20 years in the fabrication and repair of shell and tube heat exchangers.

The use of explosives to perform these expansions has offered several distinct advantages over other methods. First, the process is fast and economical and can be performed with minimal training of personnel. Secondly, explosive forming does not cause the deleterious metallurgical effects which often result from other forming operations. In addition, the process can be performed remotely without the need for sophisticated handling equipment.

The expansion of tubes into tubesheets is only one of many possible fastening and joining applications for which explosive forming can be used to achieve highly successful results.

This paper describes the explosive forming process and where it has been used. In addition, some possible adaptations to other joining applications are identified and discussed.

## INTRODUCTION

The expansion of tubes into tubesheets of heat exchangers is performed for several reasons. First, the expansions may provide the pressure seal between the primary and secondary sides of the heat exchanger to prevent mixing of the two mediums which are being heated or giving off heat. Secondly, the expansion provides the axial strength of the joint. This strength requirement may be quite large, depending upon the design of the exchanger. Lastly, the expansions close the annular gap between the drilled hole and the tube outside diameter, preventing the accumulation of possible corrodents which may attack the tube or tubesheet materials.

## TYPICAL TUBE-TUBESHEET JOINT DESIGNS

Tube-to-tubesheet joints which require expansion are generally one of the three following types, see Figure 1.

The first type uses a weld at the front face of the tubesheet that provides the pressure tight seal. The expansion is done to close the annular gap to exclude space for the accumulation of corrodents and to provide joint strength so the weld is not subjected to vibration or axial loads. This design is used for high pressure applications.

For the second type the tube is expanded for the full depth of the tube hole. The expansion provides both the seal and axial strength to the joint. This design is normally used where the pressure differential across the joint is low.

The third design incorporates circumferential grooves within the tubesheet hole. The grooves provide additional axial joint strength and also disrupt axial drill marks, thus increasing the sealing ability of the joint. This design is used for both high and low pressure applications.

## THE EXPLOSIVE EXPANSION PROCESS

The explosive tube expansion process is achieved by placing a uniform carefully sized explosive charge into an energy transmitting medium which is sized to fit the inside of the tube, see Figure 2. The length of the charge/medium package, called an insert, is the same as the desired expansion. A flange at one end of the insert facilitates proper placement with the tube bore. The continuing explosive at the front end of the insert provides the means of detonation.

The explosive generally used because of its availability, consistency and safety is detonating cord. The detonating cord, which is commercially available to many charge sizes, uses PETN (pentaerythritoltetranitrate) as the explosive core load.

The body of the insert that positions and transfers the energy from the detonating explosive is usually made from low density polyethylene. Polyethylene has been selected because of its low cost and availability. In addition the absence of halogens, sulfur and heavy metals in its constituency make it safe to use when expanding materials which may be sensitive to stress corrosion cracking.

Selecting the proper charge size to perform the expansion is achieved by conducting a series of expansions using prototypical tubes and test tubesheets. Once the optimum charge size is determined for a particular material and size combination this data is retained and used for all subsequent expansions having these parameters.

The number of tubes that can be expanded simultaneously is limited only by the noise and shock wave constraints at the expansion site. As few as one and as many as 5000 tubes have been successfully expanded in one detonation.

## ADVANTAGES OF EXPLOSIVE EXPANSION

The explosive expansion of tubes into tubesheets offers several distinct advantages over the once common practice of Mechanical rolling.

Mechanical rolling is accomplished by rotating tapered rollers, held within a metal cage, about the inside of the tube. These tapered rollers are rotated and forced toward the tube wall by a mandrel, which is also tapered, that is placed between the rollers. As the mandrel is rotated and driven inward the rollers gradually force the tube into contact with the tube hole. Additional force is applied until the tube is cold worked sufficiently to become tight within the hole. This method which can produce strong tight joints also causes severe local surface distortion to the tube inside surface. This cold work often leaves the tube very susceptible to stress corrosion caused failures in service.

Metallurgical examinations have shown that explosive expansion results in an almost undisturbed material structure as shown in Figure 3.

Mechanical expansion is also dependent upon the skill of the operator to achieve correct and uniform results. Explosive expansion, because of the consistency of the explosives used, produces the same degree of expansion each time.

The explosive expansions can be performed easily in remote or relatively inaccessible areas. Other methods require more space and access because of the size of the necessary tooling.

Finally, especially when the tubesheets are thick and the quantity of tubes large, there is an appreciable savings in the time required to perform the expansions.

## OTHER APPLICATIONS OF EXPLOSIVE EXPANSION

The expansion of tubes into tubesheets is only one of many possible applications of explosive expansion of tubular components. The process can readily be adapted to joining tubular members into an almost endless variety of structural shapes. Identified below are only a few of the possible variations.

Tubular prefabricated sections, Figure 4, could easily be assembled and the connections explosively expanded at any location to form a ladder or other structure. Properly sized explosive charges placed into the ends of the smaller tubes would, when detonated, cause expansion of this tube at both sides and the interior of the larger tube. These expansions will firmly lock these members together.

Figure 5 shows a method of reinforcing a structure by adding a truss. These trusses would also be explosively expanded in place. Strategic locations would provide an extremely rigid structure.

Figure 6 indicates how the process can be adapted to square as well as round tubing. Finally Figure 7 shows how rotation of the expanded tubular connections can easily be prevented by premachining a key or notch into the drilled hole.

The examples shown are only a few of the many possible configurations for fastening structural components using explosive forming methods. What these examples do show is that structures could be erected and securely fastened anywhere without the need for special tools or personnel skills.

For application in remote or difficult environments the explosive charges can be pre-assembled and secured into the structural members prior to delivery to the erection site. Thus the amount of handling required during actual construction is reduced to a minimum.

## CLOSURE

It has been shown that explosive forming can be used to join and fasten tubular members to form structures. The applications are endless and with the knowledge of the process in hand engineers have another tool to use when designing structures for use in the remote areas of the earth or in space.

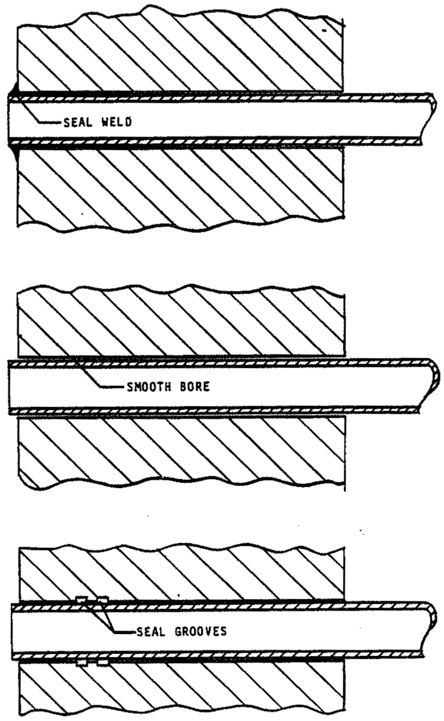


Figure 1. Typical heat exchanger tube to tubesheet joints.

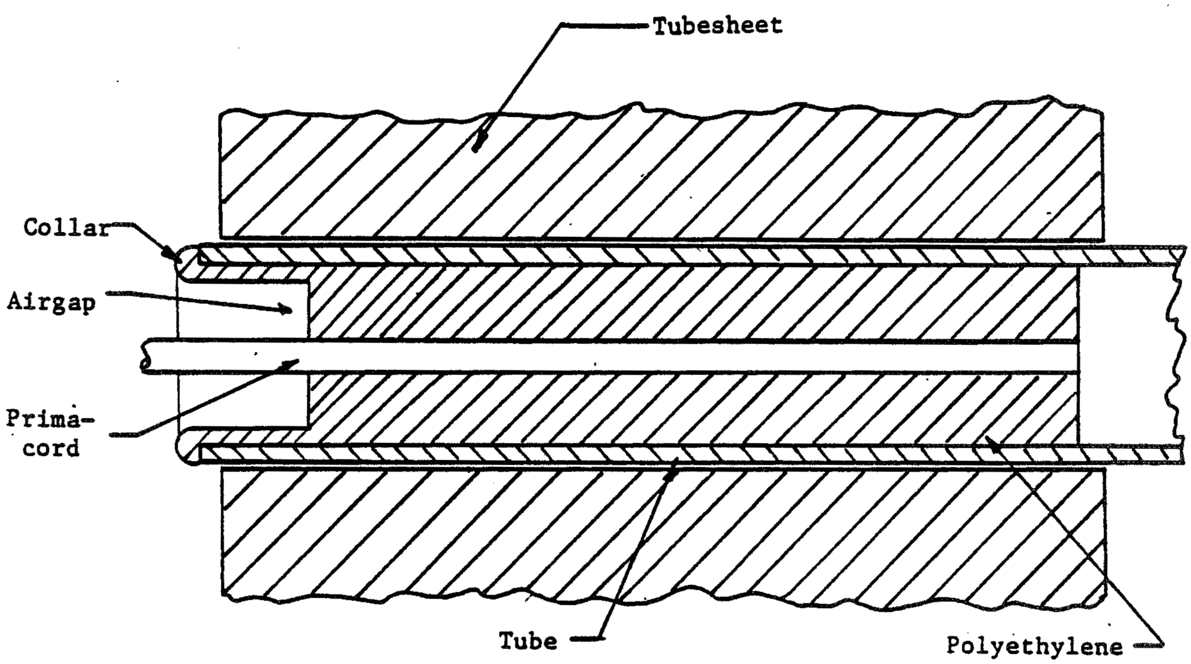


Figure 2. Explosive insert positioned in a tube and tubesheet assembly.

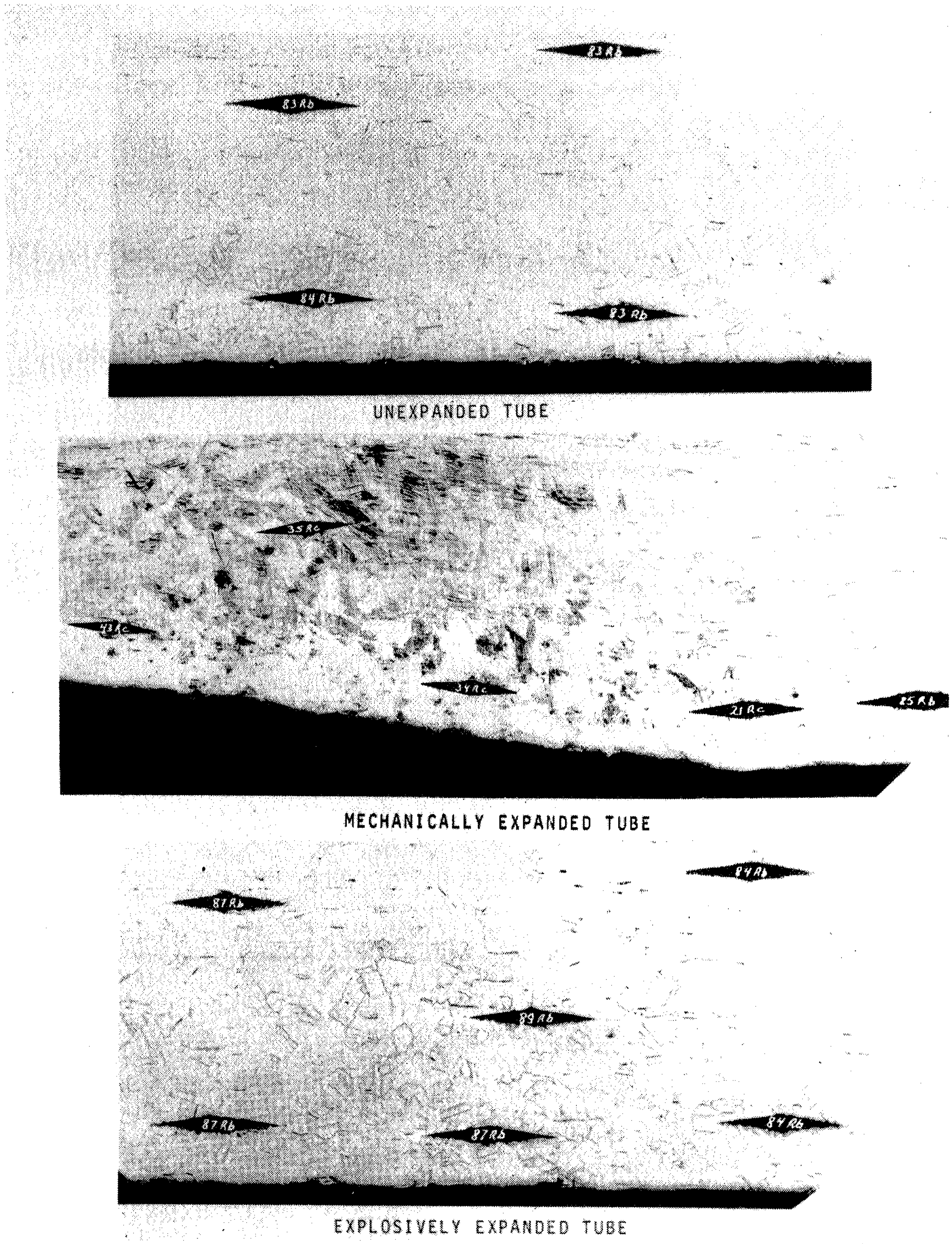


Figure 3. 100X photomicrographs showing grain structure and micro-hardness values of unexpanded, mechanically expanded and explosively expanded type 304 stainless-steel tubes.

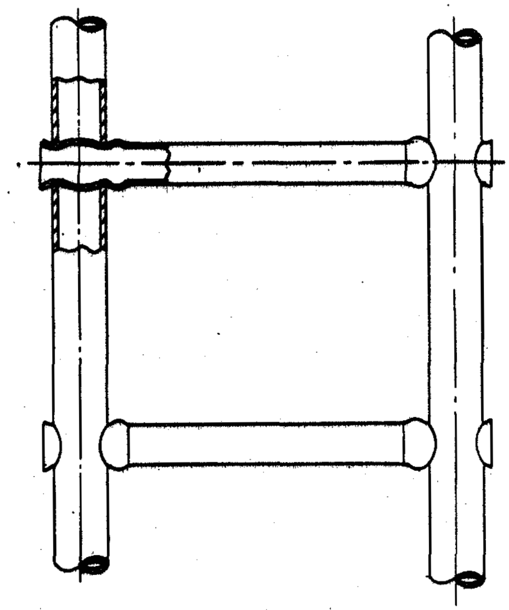

Figure 4. Assembly of tubular components to form a rigid structure.

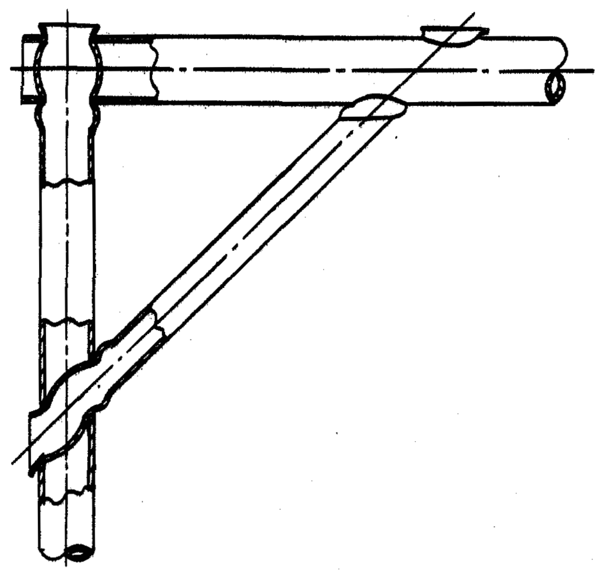

Figure 5. Reinforcement of structure by addition of a truss.

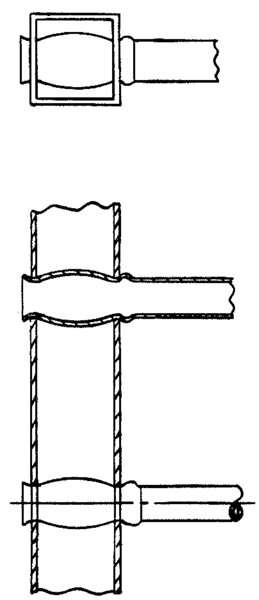

Figure 6. Application using square or rectangular tubing.

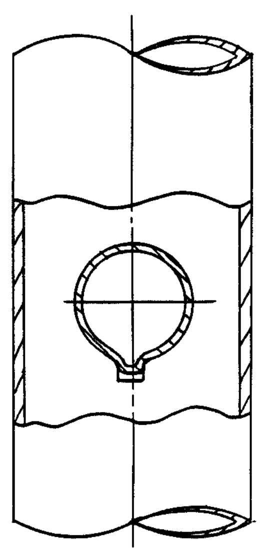

Figure 7. Method of keying to prevent rotation of round structural connections.