United States Patent [11] **3,540,529**

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[21] Appl. No. **705,410**
[22] Filed **Feb. 14, 1968**
[45] Patented **Nov. 17, 1970**
[73] Assignee **Hitachi, Ltd. Tokyo, Japan a corporation of Japan**
[32] Priority **Feb. 17, 1967**
[33] **Japan**
[31] **9,817**

[54] **WELDED ASSEMBLY OF A TUBE AND A TUBE SHEET**
4 Claims, 11 Drawing Figs.

[52] **U.S. Cl.** **165/134,** 29/157.4, 165/173, 165/178
[51] **Int. Cl.** **F28f 19/00,** F28f 9/18
[50] **Field of Search** 165/178, 176, 173, 134; 29/157.3, 157.4

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ABSTRACT: Welded assembly which comprises a tube sheet provided with at least a hole having a flared opening at one end, a tube being tightly inserted partially into the hole from the other end thereof with the top of the tube being in contact with the bottom of the flared opening, and a deposit metal to secure the top end of the tube to the tube sheet in the flared opening of the hole in which a diameter of the flared opening at the tube sheet surface being at least 1.1 times of an outer diameter of the tube, the top end of the tube being positioned at a distance from the top edge of the hole of at least one-fifth of the outer diameter of the tube, and a surface of the deposit metal being formed in bellmouthed structure.

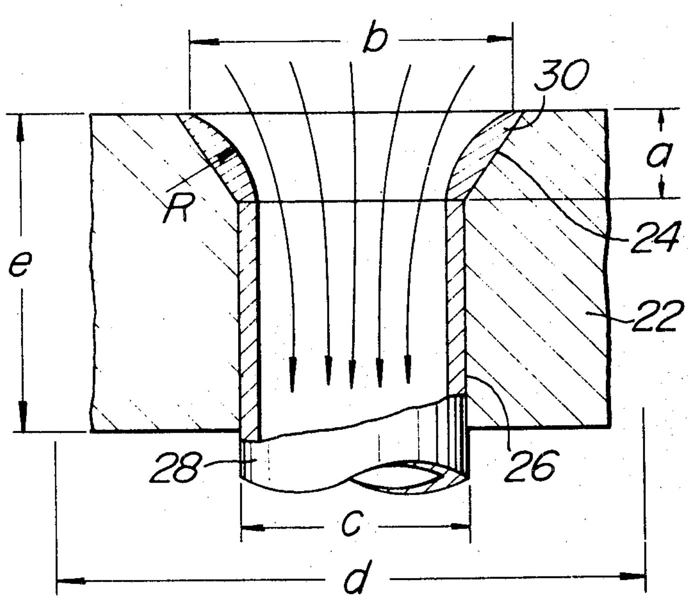

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FIG. 1

PRIOR ART

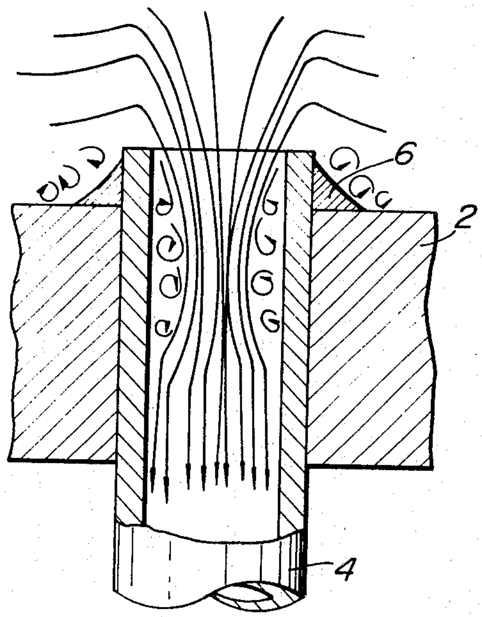

FIG. 2

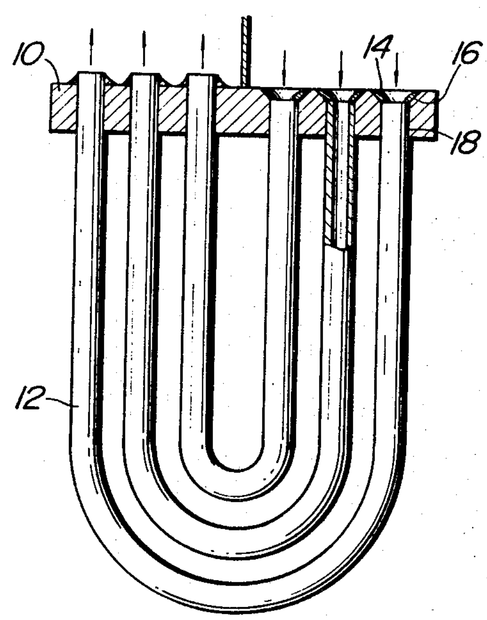

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FIG. 3

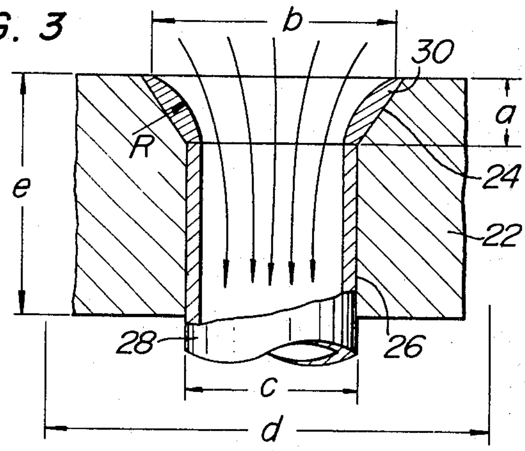

FIG. 4a

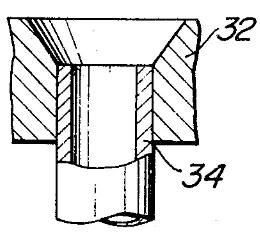

FIG. 4b

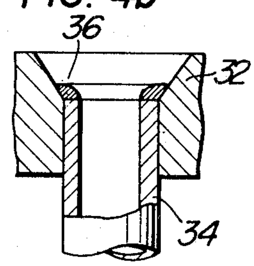

FIG. 4c

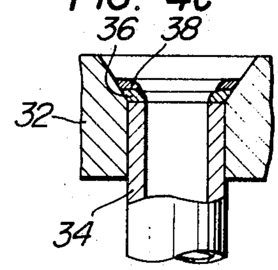

FIG. 4d

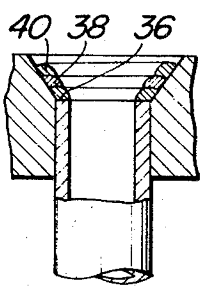

FIG. 4e

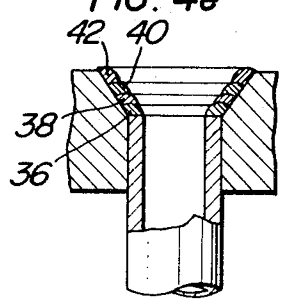

FIG. 4f

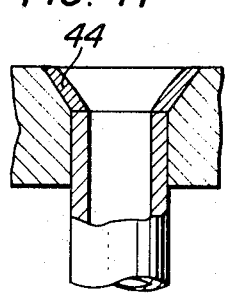

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FIG. 5

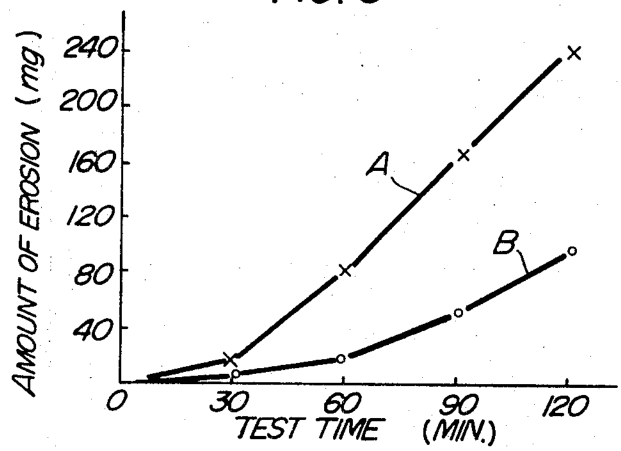
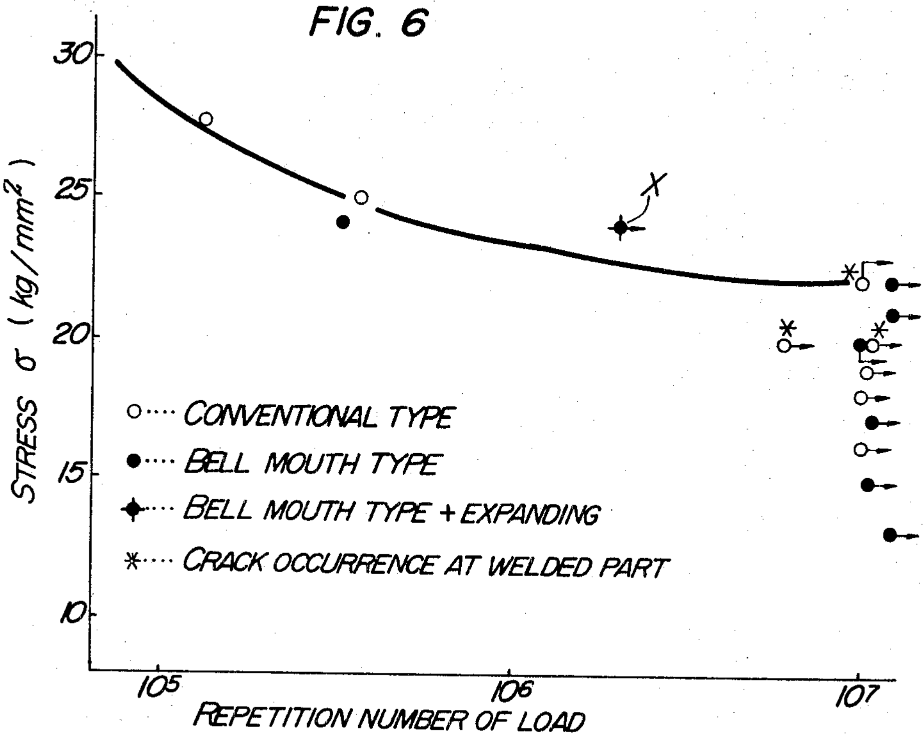


FIG. 6



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WELDED ASSEMBLY OF A TUBE AND A TUBE SHEET

The present invention relates to a means for connecting a tube to a tube sheet, and more particularly to a means for connecting a tube and a tube sheet wherein fluid such as water is circulated with high speed.

In manufacturing condensers or heat exchangers for a steam turbine plant or a refrigerating apparatus, it often becomes necessary to connect or join tubes to tube panels. In such a condenser or a heat exchanger, each tube is inserted into a hole provided in the tube sheet and connected or joined thereto by a suitable means such as mechanical fitting and sealing means or welding. When fluid such as water is circulated with high speed through the tubes and the tube sheet thus joined, an eddy or turbulent fluid flow is created and vena contracta occurs at the connection between each tube and the tube sheet or at the entrance of each tube. Thus, as a result, the inner surface of each tube and the connection between each tube and the tube sheet are eroded.

In a case wherein each tube is made of an iron-based alloy, the corrosion rate of the tube in water is determined by an oxygen dissolved in water and water temperature, and it is believed that, when there is much oxygen, a corrosion product film formed on the tube surface consists mainly of ferric oxide Fe_2O_3 but when there is less oxygen, under the temperature of 150°C. and over, ferrous oxide Fe_3O_4 is mainly produced. These corrosion product films are removed from the tube surface by the eddy current and the vena contracta, and thus a new steel surface is exposed on the tube. The newly exposed steel surface is again subjected to corrosion to form another layer of corrosion product film which is again removed from the tube to expose a successive steel surface of the tube.

Recently, for example, in a steam turbine plant, a carbon steel or a low alloy steel of low price has become to be used as a tube material for a high pressure feed water heater (H.P. heater) in lieu of a nickel-copper alloy which has previously been used, so that the above-mentioned problem of corrosion-erosion has become to be seriously considered.

Hithertofore, in the joint between each tube and the tube sheet, it has been widely employed to insert the tube into a hole formed in the tube sheet, the portion of the tube which is passed through the hole being expanded by means of an expander and fixed and sealed by a mechanical means. Further, in accordance with the tendency of increase in scale of steam turbine plant, a high pressure feed water heater has become to be operated with higher pressure. For example, in a steam turbine plant of the order of 175,000 KW/h, a high pressure feed water heater with a steam pressure of as high as 180 kg./cm.^{2} which is approximately 3,000 p.s.i. or more has become to be utilized. In such a high pressure apparatus, since a prior mechanical means for fitting and sealing a tube to a tube sheet is insufficient in sealing capability and reliability, the tube has been welded to the tube sheet. In the past, various methods have been used to make the welding. These prior welding methods have the following common disadvantages:

1. When the surface of the deposit metal of weld is worn off through the corrosion-erosion phenomenon, the pinholes and the fine cracks in the deposit metal are exposed and cause leakage of high pressure and high speed water.

2. In a connecting structure wherein a tube is merely inserted into a hole of a tube sheet and welded thereto, as already described, an eddy and turbulent flow are created and vena contracta occurs. Thus, the inlet portion of the tube and the deposit metal of the welding connection are attacked and corrosion-erosion is caused.

3. In case where the volume of the tube panel is substantial, the welded past and the zone which is affected by welding heat are subjected to a rapid cooling and result in a hardening and fragility of the material.

Thus, the corrosion-erosion caused by the eddy or turbulent flow and the vena contracta is a very important problem, so that it is necessary to smooth out the high-speed water flow at the inlet portion of each tube to obtain a laminar flow. For this purpose, there has been proposed to provide, in the tube sheet, openings having cross section of inverted bell shape, and to secure to each of the openings a so-called bellmouth-type support (or flow regulator) having a flared water inlet. However, in this arrangement, the size and weight of a water channel which houses the tube sheet substantially increases. Therefore, this arrangement is disadvantageous from the technical and economical view point and thus the guide plate such as bellmouth-type regulator should preferably be omitted. Further, as an alternative arrangement, each tube has been provided with a separate bellmouth-shaped protection tube inserted therein, but this is not satisfactory from the viewpoint of the mechanical strength, manufacturing and weight of the joint or connection between the tube and the tube sheet.

An object of the present invention is to provide an improved welded assembly which is excellent in corrosion-erosion resistance characteristics against high speed water.

Another object of the present invention is to provide a novel welded assembly between a tube and a tube sheet, which joint is extremely strong in mechanical strength.

A further object of the present invention is to provide a technique by which thermal stress at the welded assembly due to heat cycle is substantially reduced.

Still further object of the present invention is to provide a novel welded assembly in which the part affected by welding heat is not hardened.

The above and other objects, and the features of the present invention will become apparent from the detailed descriptions of a preferred embodiment taking reference to the accompanying drawings.

FIG. 1 is a longitudinal sectional view of a typical prior welded joint particularly showing eddy or high-speed water flow pattern and vena contracta causing a corrosion-erosion of the welded joint;

FIG. 2 is a partially sectioned elevational view of the construction of tubes and tube sheet employed in a heat exchanger embodying the present invention;

FIG. 3 is a sectional view similar to FIG. 1 but showing a welded joint of an embodiment of the present invention;

FIGS. 4*a* to 4*f* show diagrammatically a process for making a welded joint between a tube and a tube sheet in accordance with the present invention; and

FIG. 5 is a diagram showing the relation between the amount of the deposit metal removed by corrosion-erosion and the time. FIG. 6 shows results of creep tests for welded assembly between a tube and a tube sheet.

The principal basis of the present invention is to determine the dimensional relationship, in the welded assembly having a tube sheet and a tube inserted into a bellmouth-shaped hole provided therein, the top end of the tube being welded to the tube sheet, so that the diameter of the upper edge of the hole b, the outer diameter of the tube c, and the distance between the tube end and the tube sheet surface a have the relation of $b/c > 1.1$ and $c/a < 4$.

The basic feature of the present invention is to determine the ratio of the tube outer diameter to the distance between the tube end and the tube sheet surface, and that of the diameter of the hole upper edge and the tube outer diameter as set forth above in order that the high-speed water flowing into the tube is smoothed out to form a laminar flow without creating a turbulent flow or causing a vena contracta.

In addition to these geometrical arrangements, it should be pointed out, as the important aspects of the present invention, that the top end of the tube is welded to the wall of the hole and the deposit metal surface of the weld is smoothly machined so as to prevent the turbulence of flow and the vena contracta, and that a material which is superior in anticorrosion-erosion characteristic is used as the deposit metal.

FIG. 1 shows a typical conventional welded assembly in which a tube 4 is inserted into a hole provided in a tube sheet 2 of carbon steel so that the top end of the tube 4 projects from the tube sheet 2, the projecting top end of the tube 4 being welded as shown by the reference numeral 6 to the tube sheet 2 by means of such as argon arc welding using a mild steel welding metal. In this type of assembly, eddy currents and a vena contracta occur as shown by arrows in FIG. 1, and as a result, the water inlet of the tube 2 is attacked so that it will be worn out by the corrosion-erosion phenomenon. The wear of the top end of the tube 4 will then cause the leakage of high-speed and high-pressure water.

FIG. 2 shows, in part by elevation and in part by a section, a welded assembly produced in accordance with the present invention. The right half of the construction where the high-speed water flows into the tubes is provided with the welded joints between tubes and a tube sheet made according to this invention, and the left half where the high-speed water flows out from the tubes is provided with conventional welded joints because of the easy welding work thereof. In this example, both side of a tube **12** are inserted into a hole **18** provided in the tube sheet **10**, the top end of the tube **12** being welded onto the wall surface of the tapered opening or frustoconical position **16** formed in the hole **18** of the tube sheet **10**. A deposit metal **14** for the welding extends to the upper surface of the tube sheet **10** and has the smoothly machined surface so as to provide an inlet portion of bellmouth shape.

More detailed structure is shown in FIG. 3. The tube sheet **22** is provided with a tapered opening **24** and a cylindrical hole **26** connected thereto, and a tube **28** is inserted into the hole 26 so that it terminates at a position recessed from the surface of the tube sheet **22** by a distance greater than one-fourth of the tube outside diameter *c*. Then the top end of the tube **28** is welded to the wall of the frustoconical hole **24** of the tube panel **22**. The deposit metal **30** thus formed by the welding is then machined so as to provide a smooth surface which continues to the tube inner surface and forms an inlet portion of bellmouth shape or the like. Then, the water flows into the tube **28** in a continuous laminar flow pattern without causing any corrosion-erosion phenomenon at the tube inner surface and/or the deposit metal surface.

By determining the large diameter *b* of the tapered opening portion **24** to be equal to or greater than 1.1 times the tube inside diameter *c*, and the distance *a* between the surface of the tube sheet **22** and the top end of the tube **28** to be equal to or greater than one-fourth of the tube inside diameter *c*, creation of the laminar flow is assured. In order to assure that the laminar flow is effectively created, it is preferable to select the ratios $b/c \cong 1.1$ ** 2 and $c/a < 4$. It is necessary, in order to obtain the laminar flow, to take into account not only the shape of the frustoconical **24** of the hole provided in the tube sheet **22** but also the flow speed of the high-speed water flow. For example, in a high-pressure feed water heater (H.P. heater) in which water flows at a speed as high as 1.5 ** 3.0 m./sec., it may be desirable to determine the relations as *b* ** 1.3 *c* and *a* ** ½ *c*. Generally speaking, in case where water flows at a high speed exceeding 0.6 m./sec. more particularly 1.0 m./sec., which is approximately 3.28 ft./sec. it is recommended that the ratios to b/c is about 1.1 ** 2, $c/a < 4$.

It is further desired to consider about the shape of the opening (*i.e.* the form of deposit metal surface). For example, for a speed of water greater than 1.0 m./sec., a radius of curvature R of curved surface of the opening is preferably (0.4 ** 1.0) *c*. More particularly, the radius of curvature of (0.4 ** 0.7) *c* are recommended for 1.0 ** 3.0 m./sec. of water speed. Needless to say, the above-mentioned condition for shape of the opening only shows a general standard and in practice, the shape of an actual embodiment will be determined, machined, and corrected to be most suitable for occurrence of laminar flow.

Laminar flow may occur most probably when b/c ** 1.2 ** 1.5, c/a ** 0.3 ** 1.0 and R **0.4 ** 0.7.

By the way, in a high-pressure feed water heater being operated under a very high pressure of 180 ** 250 kg./cm.^{2}, tubes having a thickness of 1.4 ** 3.5 mm. and an outer diameter of 19 mm. or 15.9 mm. are generally employed.

It is important to select a suitable filler metal so that the deposit metal may have a sufficient anticorrosion-erosion characteristics. Further, care must be paid so that the deposit metal may not receive any thermal effect by a rapid cooling after welding and may not be hardened or get fragility. It is preferable to perform the welding in such a manner that the deposit metal and the welded portions of the tube **28** and the tube sheet **22** may have wholly or mainly an austenitic structure. Namely, it is preferable to use a filler metal comprising such an alloy that includes nickel, manganese or cobalt since these are known to be effective to lower the A_3 transition point and extend the austenite region. By using such a material, austenitic structure can be maintained even when iron atoms dilute the nickel amount ratio of the deposit metal. For example, alloy steel having 18 percent Cr and 8 percent Ni, those having 25 percent Cr and 35 percent Ni, those having 15 percent Cr and 50 percent Ni, those having 25 percent Cr and 20 percent Ni, and Inconel are considered to be suitable as the filler metal. Inconel includes 70.0 ** 76.0 percent of Ni, 13.0 ** 17.0 percent of Cr, 6.0 ** 12.0 percent of Fe, 0.5 ** 2.0 percent of Mo, 1.0 ** 3.5 percent of Mn, less than 0.015 percent of S, less than 0.75 percent of Si, and less than 0.1 percent of C. Molybdenum is known to be effective to reduce the crack-sensitivity of the heat affected zone, but since niobium also has the same effect, the Inconel added with 2.0 ** 3.0 percent of niobium may also be used.

From the viewpoint of the anticorrosion-erosion characteristics of the deposit metal, a filler metal including more than 20 percent and preferably more than 50 percent of nickel. In such an apparatus wherein the welded joint is not subjected to a severe heat cycle, the thermal expansion coefficient of the deposit metal may not be so important. However, in case such as a high-pressure feed water heater, it is necessary to use a filler metal which will produce a deposit metal having a thermal expansion coefficient substantially equal to those of the tube panel which may be produced, from the economical standpoint, from carbon steel (0.26 percent of carbon, 0.35 percent of silicon and 1.0 percent of manganese) and of the tube which may be produced from low carbon alloy steel (such as a 0.5 percent Mo steel). In such a case, Inconel including about 70 percent of nickel is believed to be particularly excellent filler metal. When a tube of low carbon alloy is welded to a tube sheet of carbon steel by using such a filler metal of high nickel content, the welding deposit metal will have mainly austenitic structure, and moreover, the layer which is formed by the deposit metal being molten into the material of welded parts (penetration region) will mainly be constituted by the austenitic structure, so that the deposit metal has excellent anticorrosion-erosion characteristic, and the heat affected zone will not be hardened and thus the possibility of being cracked is substantially reduced. Still further, the thermal expansion coefficient of the deposit metal produced by using a filler metal of high nickel content is about 11.5×10^{-6}/°C. and is close to that of carbon steel which is about 11.2 ** 11.5×10^{-6}/°C., creation of thermal stress due to heat cycle at the welded joint can be limited to a minimum.

As a tube material, as well as 0.5 percent Mo steel, low carbon alloy steel such as 1 Mo steel, 2½ Cr ** 1 Mo steel or the like may economically be used. The materials for the tube and the tube sheet should be selected from the viewpoints of economy, welding characteristics and etc., and it is not intended to limit the tubes to the above-described materials.

FIGS. 4*a* to 4*f* show a process for making a welded assembly of the present invention. As shown in FIG. 4*a*, a tube sheet **32** is provided with a tapered opening and in which a tube **34** is inserted. A diameter of a cylindrical hole into which a tube is inserted, is not necessary equal to the outer diameter of the tube. That is, the diameter of the cylindrical hole may be greater than the outer diameter of the tube so that the tube may be easily inserted into the hole. A gap between the hole and the tube may be eliminated and the outer surface of tube may be secured tightly to the hole surface by expanding the tube by means of an expander. As previously described, a suitable material is selected for filler metal in accordance with the materials, application and purpose of the tube and the tube sheet. Then, as shown in FIG. 4*b*, the top end of the tube **34** is welded to a bottom of the wall of the tapered portion of the bellmouth-shaped hole. In FIG. 4*b*, the deposite metal formed by the aforementioned welding process is shown by the reference numeral **36**. Thereafter, similar welding process is repeated to form deposit metals **38**, **40** and **42** as shown in FIGS. **4***c* to **4***e*. During this welding operation, the materials at the surfaces of the tube end and the tube sheet melt or penetrate into the material of the deposit metal. By thus making welding not only at the top end of the tube **34** but also at the whole surface of the tapered opening of the bellmouth-shaped hole of the tube sheet **32**, sufficient amount of deposit metal melts or penetrates into the materials of the tube and the tube sheet and contributes to increase the sealing ability and the tensile strength of the joint between the tube **34** and the tube sheet **32**. This is of course advantageous from the viewpoint of anticorrosion-erosion characteristics. The deposit metal thus formed is then machined so as to provide a smooth and bellmouth-shaped surface. It is one purpose of the present invention to form a surplus deposit metal of good anticorrosion-erosion characteristics on the surface of the tapered portion and to machine it into a smooth and bellmouth-shaped surface. The welding may be performed by TIG welding method with 5—10 l./mm.^{2} of argon flow amount and 80** 100 ampere of electric current. Welding can be performed by hand operation, semiautomatic operation, or any other methods. It is preferable that the welding of the first layer is performed carefully by hand operation so as to secure the penetration into the deposit metal of welded portions. After that the welding may be carried out by semiatomatic welding so that the welding may be efficiently performed. The deposit metal is preferably formed in five to seven layers taking the relation of c/a into account. This is also important in order to obtain a sufficient melting or penetration of the deposit material into the materials of the tube **34** and the tube sheet **32**. The amount of corrosion-erosion of the deposit metal was measured with respect to a welded joint formed by using a filler metal of Iconel No. 92 and that formed by using a filler metal of mild steel (Ox weld No. 65 in the table of Linde Company). The result is shown in FIG. 5. In this FIG., the curve A shows the result obtained with respect to the welded joint formed by using Ox weld No. 65 as the filler metal and the curve B shows the result obtained with respect the welded joint formed by using Inconel No. 92 as the filler metal. The test was performed at water temperature of 25°C. and the amplitude of the tube was 120μ. From the data, it can be seen that the welded joint in accordance with the present invention has an excellent anticorrosion-erosion characteristic.

Further, autoclave tests were performed by heating in the degased water of pH 9.3 for 200 hours. The results are shown in table 1.

TABLE 1.—AMOUNT OF CORROSION—EROSION

	Mg./mm.^{2}	
	150° C.	200° C.
0.5 Mo steel	0.05	0.10
0.5 Mo steel piece welded by Inconel	0.03	0.05
0.5 Mo steel piece welded by Oxweld	0.05	0.18
Inconel	0.02	0.02

Further, the mechanical strength of the welded joint between the tube and the tube sheet as shown in FIG. **3**. The results are shown in table **2**. In this test, the dimensions of the sample were $a = 8$ mm., $b = 20$ mm., $c = 16$ mm., $d = 50$ mm., and $e = 100$ mm., and the tube length was 232 mm., thickness of tube 2 mm.

TABLE 2

Point of rupture	Yield strength, kg./mm.^{2}	Tensile strength, kg./mm.^{2}
At steel tube	34.2	50.9
At steel tube	34.2	50.7

From the above data, it can be seen that the welded joint in accordance with the present invention is very strong. The fact that the breakage occurs at the steel tube but not at the welded joint clearly shows that the welded joint is stronger than th steel tube.

Furthermore, the inventors conducted creep tests of welded joints made according to the present invention. The results are shown in FIG. **6**. Specimens for the test were those shown in FIG. **1** and FIG. **3** and predetermined amounts of stress were applied to welded joints by means of repetitions load to lower portions of tubes extending below the tube sheets. The test results were examined by occurrence of cracks in the welded joints or tubes. As will be clear from FIG. **6**, conventional type welded joints yield cracks at a low repetition number of applied load and on the contrary, welded joints according to the invention does not yield any cracks therein even beyond **10**^{7} repetition number of applied load. The point X in FIG. **6** shows a case that similarly to the actual products of this kind, high-speed water inlets were formed into bellmouth shape and inserted portions of tubes were expanded by an expander radially so as to tightly fit into the hole of the tube sheet. This results shows that welded joints according to this treatment can withstand higher stress beyond a considerable amount of repetition number of applied load. The other points in FIG. **6** show cases where inserted portions of tubes were not expanded, and small gaps existed between the tubes and the surface of the holes, so that precise strength of the welded joints may be determined.

The welded joint in accordance with the present invention is simple in construction, easy and inexpensive to manufacture. In the past, there has been proposed to overlayered deposit Iconel material on a carbon steel plate and thereafter drill a hole for inserting a tube. As compared with this prior method, the welded joint of the present invention is much more economical, because of the amount of consumed Iconel is very small.

Inasmuch as the above descriptions relate to limited embodiments of the present invention, it should be understood that the descriptions in no way limit the scope of the present invention. For example, the hole drilled in the tube sheet should not necessarily be of tapered shape as shown in FIG. 3 and FIG. 4 when it is drilled, but it will suffice that the deposit metal is machined at its surface so as to provide a bellmouth-shaped surface.

We claim:

1. A welded assembly for being subjected to high-speed water flow, said flow having a speed higher than 3 ft./ sec., temperatures higher than 150°C., and a pressure higher than 3,000 p.s.i., comprising:

tube sheet means provided with a plurality of through apertures and made of a material selected from the group consisting of carbon steel and low alloy steel, each of said apertures including an outwardly tapered portion extending from a first surface of said tube sheet means to a predetermined depth recessed from said first surface of said tube sheet means, and also including a substantially cylindrical section extending from the recessed end of said outwardly tapered portion to a second surface of said tube sheet means;

a plurality of tubes made of a material selected from the group consisting of carbon steel and low alloy steel, each disposed within said substantially cylindrical section of a respective one of said plurality of apertures;

a deposit metal provided on the tapered surface of said tapered portion of each of said plurality of apertures securing each of said tubes to the surface of the respective aperture, the surface of said deposit metal defining a bellmouthed structure;

wherein the diameter of each of said apertures, at said first surface of said tube sheet means, is about from 1.2 to 1.5 times the outer diameter of each of said tubes and the end of each of said tubes is recessed from said first surface of said tube sheet means by a distance of from 0.3 to 1.0 times the outer diametric dimension of each of said plurality of tubes; and wherein the surface of each of the openings formed in the bellmouthed structure has a radius of curvature of from about 0.4 to 0.7 of the outer diametric dimension of the corresponding tube.

2. A welded assembly according to claim 1, wherein the deposit metal has an austenitic structure.

3. A welded assembly according to claim 1, wherein the deposit metal includes a nickel base alloy.

4. A welded assembly according to claim 1, wherein said plurality of tubes are formed from carbon steel and said tube sheet means is formed from a low alloy steel containing less than 0.4 percent by weight of carbon and 1.5 percent by weight of molybdenum.