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Radial Friction Welding

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THE CONVENTIONAL FRICTION-WELDING PROCEDURE of rotating one component against another while an axial thrust is being applied is well known. Autogenous welds in the solid state are made in one operation. The procedure is an accepted production joining method because it provides excellent weld quality and good productivity, it allows the use of unskilled labor, and it enables a wide range of similar and dissimilar metal combinations to be joined. However, continuous-drive and stored-energy (inertia) friction-welding systems have not been as successfully exploited for the joining of long, hollow sections, where restrictions in the bore cannot be tolerated.

The difficulties involved in rotating an intermediate length of hollow section, and in applying uniform and consistent welding forces to both weld interfaces, represent some of the problems that face the machine designer. Furthermore, because two internal upset metal collars are formed, additional machining of the bore is necessary in order to avoid restriction. In 1975, a new approach, called radial friction welding (Ref 1), attempted to provide a means for overcoming these limitations.

Method. The radial friction-welding process adopts the principle of rotating and compressing a solid ring around two stationary pipe ends (Fig. 1a). The pipes to be welded are bevelled to provide a "V" groove when they are butted together. They are then securely clamped to prevent axial and rotational movement. A solid, internally bevelled ring of compatible material with a bevelled angle that is less than that of the pipes is positioned around the pipe ends.

The "V" groove for the 108 mm (4¼ in.) outside diameter by 9.5 mm (⅜ in.) wall thickness pipe is typically 100°, while the internal bevel of the ring is 80°. It is important for the latter angle to be less than that of the groove in order to limit the initial peak torque and also to promote metal flow from the bottom of the groove in an outward direction toward the outside diameter. Optimum angles for selected sizes of tubes and pipes are determined experimentally.

A support mandrel is located in the bore at the weld position, in order to prevent both the flow of metal into the bore and the collapse of the pipe ends. The ring is then rotated and subjected to radial compressive loading in order to obtain the frictional interaction between the rubbing surfaces, which, in turn, will generate the thermomechanical conditions necessary for weld formation. After a predetermined heating duration, the ring rotation is terminated. The level of compressive load is then either maintained or increased to consolidate the bond. Alternatively, it is also feasible to change the direction of deformation (Fig. 1b). Thus, by providing an expansion load to the ring, the ring can be deformed radially outwards to make the weld.

The included, or bevelled, angle of the solid-compression ring (Fig. 1a) or the expansion ring (Fig. 1b) can have a pronounced effect on weld integrity. The joining of the abutted area is effected and promoted by metal flow from the bore to the outer surface of the pipe. There can be little or no penetration at the pipe root. If the included angle is too narrow, the result will be a weak bond area at the weld root, leading to poor weld strength and a short fatigue life.

Process Development. It was first necessary to prove that the concept of both rotating and compressing/expanding solid rings was feasible. Consequently, conventional friction-welding machines that could provide both rotary motion and axial force were used in the initial development trials. Various bolt-on units were designed, built, and then fitted to these machines.

The results of these initial experiments are summarized in Fig. 2. Although the units were relatively simple, the concept was able to produce sound, solid-state welds with a variety of material combinations. One important outcome of this development effort was that nickel-base alloys were identified as being necessary for the internal mandrel, because they provided good resistance to radial compression loads and wear at the elevated temperatures that were attained during welding. Additional information is available in the section "Prototype/Production Machine" in this article.

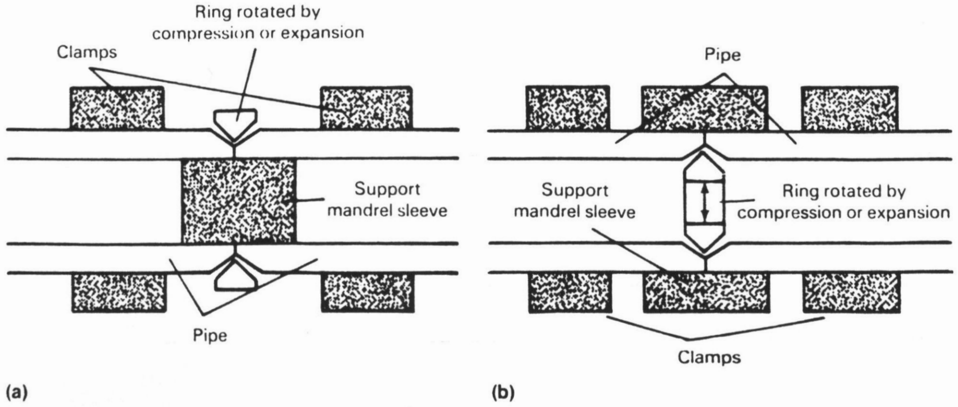

Fig. 1 Radial friction welding. (a) Using compression. (b) Using expansion

Equipment

When a prototype radial friction welder was built in the mid-1970s, the primary emphasis was directed toward the application of pipe joining. From the early experimental trials, it was recognized that the shortcomings of using this process in production would be:

- The need for axial movement of the ring through a taper housing
- The additional machining of drive grooves in the ring
- The relatively complex ring geometry, which would include a taper surface on its periphery

Consequently, the idea of using circumferentially located individual jaws (similar to multijaw collet chucks) to provide radial compression and rotation of simple rings was considered. An

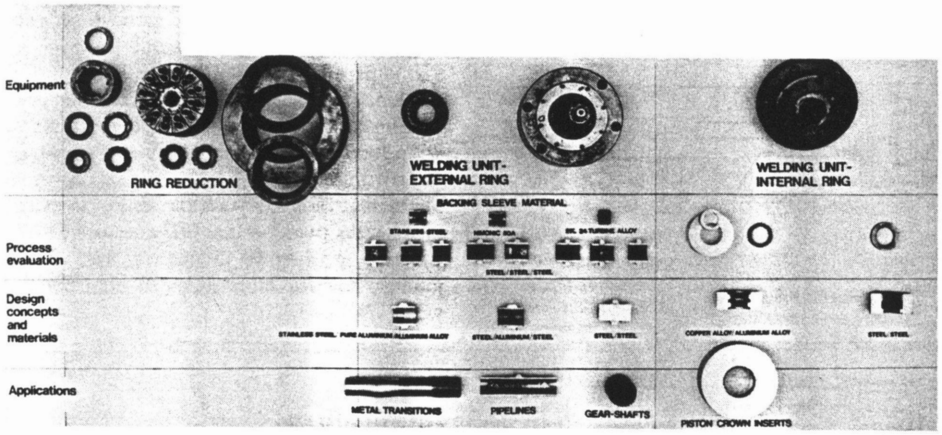

Fig. 2 Process evolution of radial friction welding

evaluation program using the arrangement (Ref 2) proved to be successful and, thus, provided the impetus to design and construct a prototype machine based on the multijaw rotation/compression arrangement.

Research Machine. A unique friction-welding facility was developed in order to join pipe of maximum dimensions, that is, 51 mm (2 in.) in outside diameter (OD), by 6 mm (0.24 in.) in wall thickness. The resulting machine is shown in Fig. 3 and its major features are described below.

Welding Spindle. It was imperative that the ring rotation/compression unit, or welding spindle, be capable of exerting a grip on the ring that was adequate for the transmission of welding power during rotation and of delivering a radial compressive force to reduce the ring into the weld groove. The welding spindle was supposed to incorporate a multijaw arrangement. The heavy steel body of the welding spindle, which needed to contain the radial compressive forces, was supported at each end by simple bearings, and was rotated through a "V"-drive pulley on its outside surface. The spindle was fixed in the machine frame using two simple yoke clamps. A hydraulic caliper disk brake unit was incorporated, when necessary, to assist ring deceleration.

An electric motor rated at 56 kW (75 hp) provided rotation to the welding spindle via a clutch and transmission. The latter enables the setting of rotation speeds ranging from 700 to 2000 rev/min, after a suitable selection of pulley ratios. The clutch and final belt drive were located in line with the welding spindle. The inside of the welding spindle housed an annular piston, which moved in an axial direction, when actuated by hydraulic means, to operate the 12 ring compression jaws via wedges. A maximum axial load of 350 kN (7.8 × 10^4 lbf) could be generated when oil was supplied to the piston through a rotary oil distributor, at a pressure of 3.4 MPa (0.5 ksi).

The welding spindle had a 340 mm (13.4 in.) OD and was 595 mm (23.4 in.) in length. Consequently, the pipe that passed through it had to be supported close to the weld area by a manually operated collet assembly at the center of the welding spindle.

Pipe Clamping. In order to react to both the axial and torsional forces generated on the pipes, four clamps (two for each pipe) were housed in the top bed of the machine (Fig. 3). The clamps opened and closed by the vertical movement of hydraulic rams that forced wedges between the pivoted jaws. These rams are capable of exerting a maximum thrust of 200 kN (4.5 × 10^4 lbf).

The machine framework was manufactured as two main assemblies. The machine bed was a heavy-section box-type fabrication that housed the welding spindle and pipe clamps. In contrast, the support framework was of a lighter construction in order to accommodate the motor drive, transmission, and other auxiliary equipment.

Hydraulic Services. The hydraulic circuit had a conventional layout, in that all services were supplied from a dual pump. A gear pump that operated at a pressure of 13.8 MPa (2 ksi) supplied the clutch, bore support mandrel, and moving carriage, whereas a high-volume vane pump that was set to provide a maximum pressure of 3.4 MPa (0.5 ksi) fed only the welding head through a flow-control valve, in order to operate the axially moving annular piston. The latter pump was used to develop the radial compressive forces on the ring. The flow-control valve could be set to provide different rates of piston movement and, thus, varying radial displacement rates to the ring.

Electrical Services. The electrical circuit utilized standard machine controls with relays and timers to sequence the operation of the initial ring preload pressure, the weld heating cycle, the disk brake, the application of forge force, the compression jaws, the mandrel, and the retraction of the moving carriage.

Internal Support Mandrel. The ideal arrangement for a support mandrel should include materials that possess good wear resistance at elevated temperatures and the capability to expand and contract from the pipe bore. The ability of the mandrel to expand proved to be useful to both round and size the pipe ends prior to welding. However, problems were anticipated during the development effort because of the limited working area available for the 50 mm (2 in.) OD pipe (that is, the 38 mm, or 1.5 in., bore), and because of the requirement to eliminate longitudinal gaps in the mandrel.

An expanding mandrel that closed 1 mm (0.039 in.) below the minimum bore diameter was devised. It was operated by a hydraulic cylinder through a draw bar. The mandrel consisted of six segments machined from a nickel-base superalloy (Nimocast PK24). Earlier trials had proved the suitability of this material. Three of the segments were used as wedges, and all segments were operated by the tapered cone on the draw bar, with the wedge segments being removed by the extraction cone first, upon release of the mandrel.

The operating sequence to produce a weld was determined to consist of the steps described below. First, both pipes and ring were machined

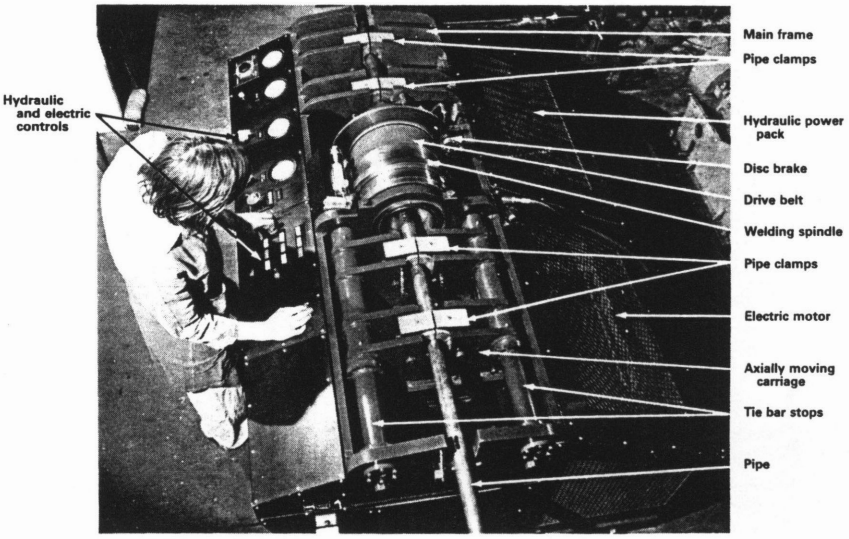

Fig. 3 Radial friction-welding machine with a 51 mm (2 in.) diameter

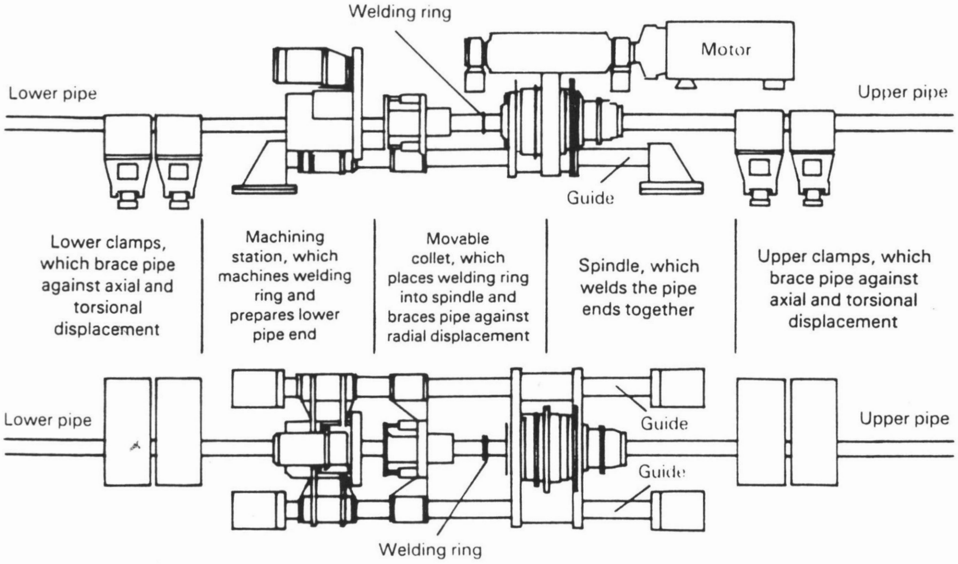

Fig. 4 Schematic of the prototype radial friction-welding machine

to provide the necessary weld groove and bevel, respectively. Then, the 16 mm (0.630 in.) wide ring was located in the reduction jaws and held under a light preload pressure.

Next, one pipe was positioned in the welding spindle and clamped, while the collet-steadying device was locked. (The collet-steadying device is of tubular construction and located around that portion of the pipe positioned inside the radial compression. When activated, it provides additional support to the pipe.) Then, the second pipe was fitted with the bore support mandrel, loaded into the machine, and clamped so that it butted against the other pipe.

After setting the rotation speed, as well as the friction welding force timing device that controlled heating duration and the flow-control valve that provided a fixed rate of piston movement (compression rate), the weld sequence was initiated. Upon completion of the weld cycle, the reduction jaws were retracted and the mandrel was sequenced to be extracted after 5 s. To remove the welded pipe, the collet-steadying device was released, along with both pairs of clamps.

Subsequent trials with this research machine demonstrated that the radial friction-welding process could produce welds of acceptable mechanical and metallurgical properties (Ref 3), and that the process could operate in the field, either on land or offshore.

Prototype/Production Machine. During the 1980s, a Norwegian company continued with the development of the process. Its efforts culminated in the design, manufacture, and subsequent commissioning of a prototype/production machine that could weld pipes ranging in size from 89 to 170 mm (3.5 to 6.625 in.) (Ref 4). This machine, which was constructed by another firm based in Oslo, Norway, was designed on a twin tie-bar arrangement, upon which the welding head and pipe clamps were mounted (Fig. 4). The welding head, which consists of the drive spindle for rotating the ring, is driven by a 370 kW (500 hp) direct-current motor. The pipe clamps operate hydraulically, as does the ring compression. Additional pipe support and alignment are provided by collets located near and inside the welding head. Although it is not yet fitted as such, the machine has space for a machining station to allow the removal of excess ring/flash metal soon after welding.

In a parallel effort to the development of this machine, special compression rigs for radial friction welding were manufactured to interface with 1000 to 1800 kN (110 to 200 tonf) axial thrust friction welders. These units provide experimental facilities with the ability to evaluate the process over a wider OD size range (100 to 273 mm, or 4 to 10.75 in.), not only for pipe joining, but for other areas of application, as well.

Applications

The applications that would be suitable for radial friction welding are:

- Attachment of collars to shafts
- Welding of rotating driving bands to artillery shells
- Attachment of wear/support rings onto cylindrical bodies
- Pipe joining at both land and offshore sites
- Fabrication of shafts or pipework systems with correct alignment of parts
- Repair of pipelines, both above water and underwater
- Manufacture of bimetal transitions using a compatible intermediate material
- Insertion of nonmagnetic center pieces
- Insertion of better heat- or wear-resistant materials into diesel piston combustion bowls

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