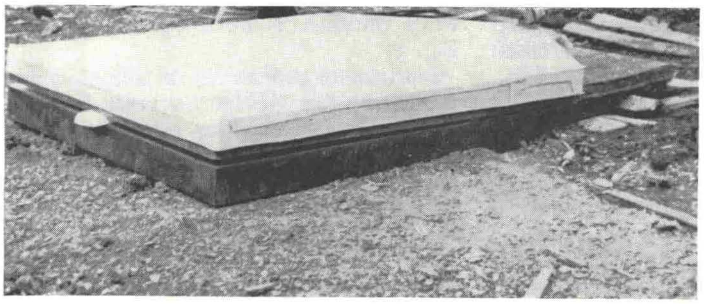
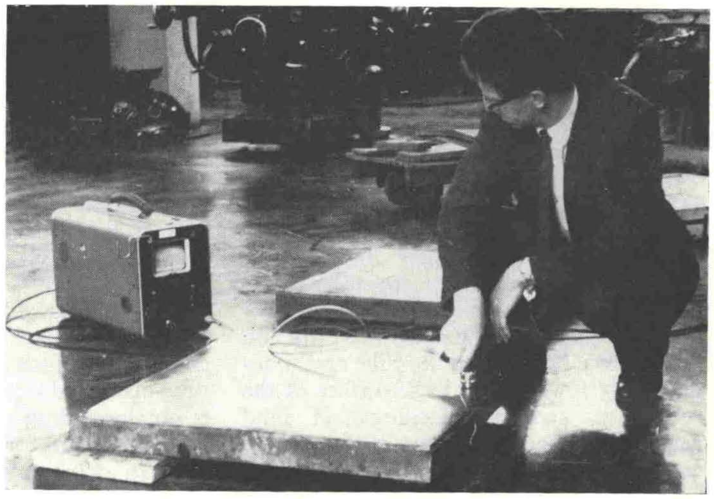


25 Arrangement for explosive cladding [3 ft-(1 m) square steel base with ½ in-(12·7 mm) thick aluminium bronze.]



26 Testing the finished product.

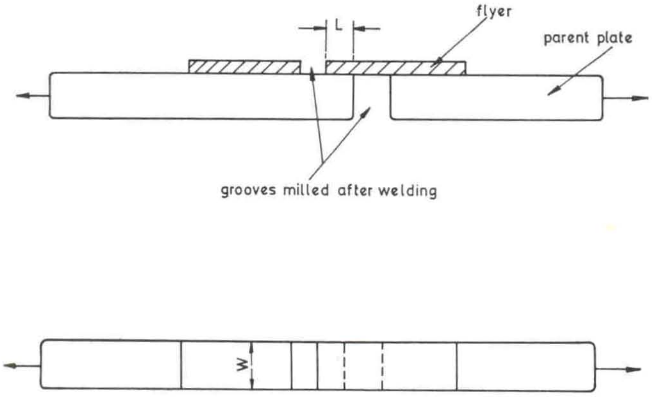
the specimen will bend through 180° without failure of the bond. De Maris gives data for fatigue tests on cantilever specimens of *Inconel* welded to ASTM A-302-B FbQ steel; the fatigue results lay between the *S/N* curves for the two materials before cladding, and the fractures did not initiate at the interface. With other combinations he noted a slight weakening of the flattened and stress-relieved clad material compared with the steel of the parent plate, but he attributed this to a reduction in hardness of the steel. Gelman *et al.* clad constructional steel with other steels and in general found a reduction of fatigue strength, which was, however, improved by a subsequent heat-treatment. Banerjee carried out repeated tension fatigue tests on stainless steel clad to steel; the results are shown in Fig. 31, where it will be seen that the fatigue strength of the clad plate is marginally greater than that of either stainless steel or mild steel. He obtained similar results for brass clad to steel. Banerjee also considered thermal fatigue by subjecting clad plates of stainless and mild steel and brass and steel to 10 cycles of heating and cooling. Each specimen was cycled to a different maximum temperature and then side shear tests were carried out. A very slight reduction in shear strength of the specimen subjected to 10 cycles of 15 to 700° C (288 to 975 K) was noted, but this could have been attributed to recrystallisation.

A problem with explosively or conventionally clad plate is the non-destructive testing of the plate to establish weld integrity. Very few techniques are available and perhaps the only one readily available is ultrasonics, though Dewy[50] shows an isothermal plot of poorly bonded nickel plating on steel established by a thermographic method which might be applicable to clad plate. Addison *et al.*[44] concluded that ultrasonic inspection is the most promising method; they submerged the plate in water between the transmitter and receiver rather than adopting the more normal reflection technique in which the crystal operates as a transmitter and receiver. Banerjee[49] carried out ultrasonic testing of plates and showed that it was possible to detect areas of poor bond or no bond. He could not detect a cast interlayer or an undesirable intermetallic compound at the interface. It must be concluded that the inspection of either roll-clad or explosively clad plate can only reveal areas of no bond, but not areas of weak bonding caused by unfavourable metallurgical conditions.

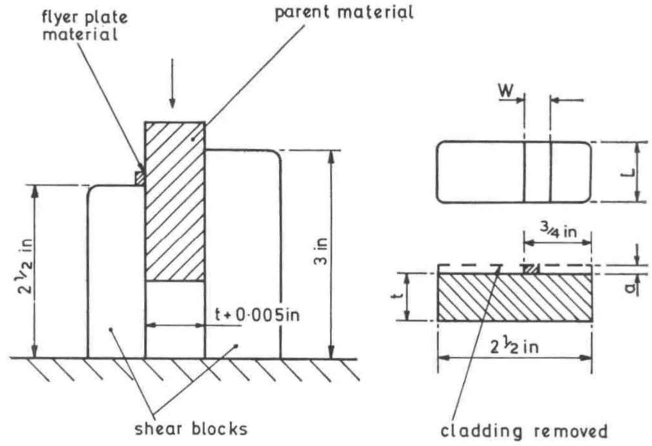
III. Tube welding

The cladding of the inner surfaces of tubes and cylinders was mentioned at about the same time by Philipchuk,[1] Wright and Bayce,[20] Carlson,[23] Holtzman and Cowan,[21] and later by Dalrymple and Johnson.[51] Philipchuk used an outer tube knurled at the bore and supporting an inner tube with a smooth outer surface, as shown in Fig. 32. The other workers adopted the arrangement shown in Fig. 33.

The application of explosive welding of tubes to tube plates has only recently been mentioned by Crossland *et al.*,[52] Chadwick

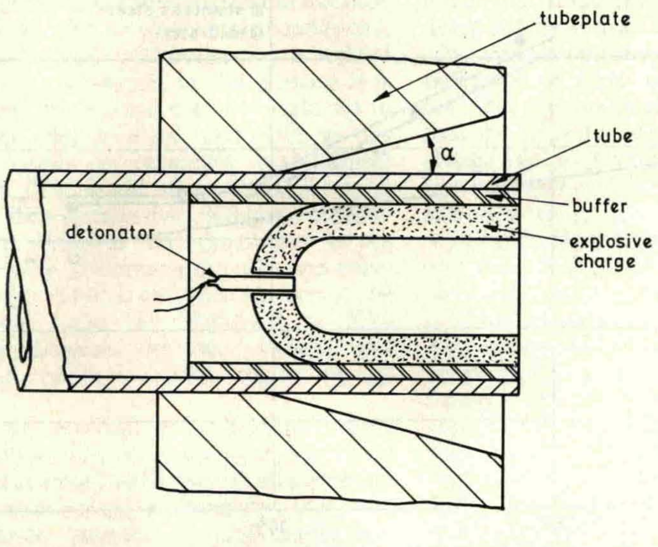


27 Specimen for tensile shear test on cladded plate.

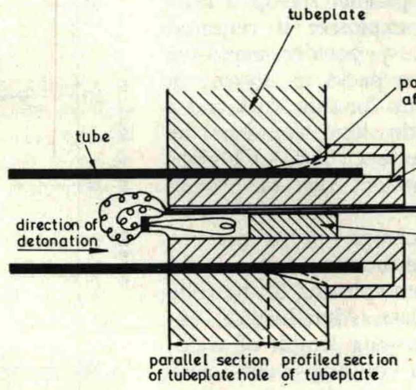


28 Shear tests on clad plate. Test-specimens: $t > 2W$; $W = 1\frac{1}{2}a$.

in	0·005	¾	2½	3
mm	0·127	19·1	63·5	76·2



34 Tapered-hole technique. (Before detonating the explosive charge).

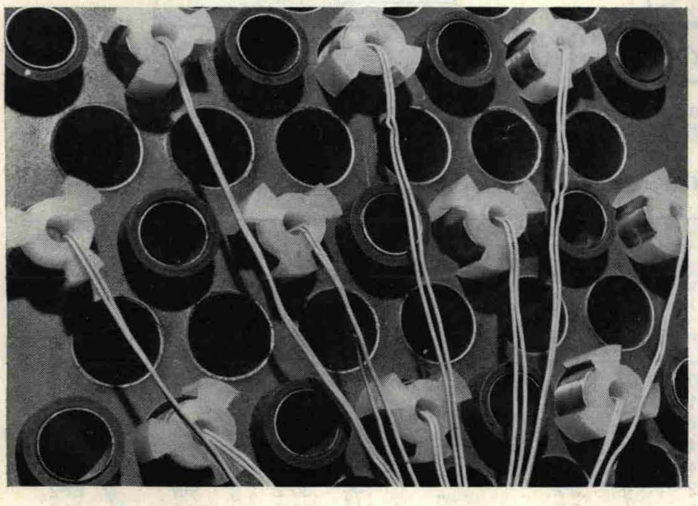


[Courtesy Welding Inst.

35 Schematic diagram of assembly for explosive welding (*YIMpact* system). (*Cairns and Hardwick.*[54])

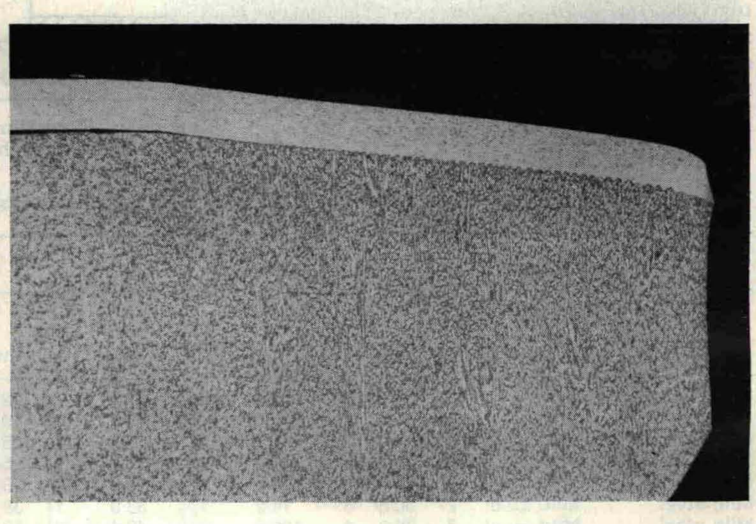
So far, data are not available for the radial velocity imparted to the tube wall immediately before impact. Chadwick[36] considers that the equations for estimating the velocity of the flyer plate in cladding are equally applicable to tube welding, though as in that case the charge is more confined this may not be true. If the minimum charge weight for a reliable weld is determined, then the minimum ligament thickness can be established for which the distortion in adjacent unwelded tube holes is acceptable.

Chadwick *et al.*,[53] Cairns and Hardwick,[54] and Robinson *et al.*[59] have discussed methods of testing the integrity of the welds between tube and tube plates obtained by the angular-geometry method. Chadwick *et al.* reported on push-out or pull-out tests on tubes in which a plug was used to try to push out a length of 1¼ in (31·8 mm) of ¾ in (19·1 mm) O.D. × 0·040 in (1 mm) wall thickness stainless-steel tube from a mild-steel tube plate. A load of 18 tonf (180 kN) was applied without failure of the bond at 20° and 600° C (295 and 875 K), and after quenching 200 times from 600° C into hot water. Peel tests have also been conducted but peeling stops abruptly in the weld zone and ultimately the strip breaks without failure of the bond. In shear tests failure occurs away from the weld interface. Chadwick *et al.* also mention fatigue tests in which the tube/tube-plate joint was subjected to repeated bending and satisfactory results were achieved. Cairns and Hardwick also carried out thermal-cycling tests in which three aluminium-brass tubes were welded into small tube plates at each end. The tube plates were connected by steel tie-bars and the whole assembly was then subjected to 10 cycles at a given temperature, followed by a hydraulic-pressure test applied to the outside of the tubes. The explosively welded tubes showed no signs of leakage even up to a cycling temperature of 450° C (725 K), whereas roller-expanded joints showed a significant decrease in the leakage pressure above 200° C (475 K) and they were completely ineffectual above 250° C (525 K). Robinson *et al.* describe manual and automatic ultrasonic tests of tube-to-tube plate welds that give results which are confirmed by metallography, peel, and leak tests. However, the method cannot detect unfavourable metallurgical conditions at the interface, such as a cast interlayer or brittle intermetallic phases.



[Courtesy Welding Inst.

36 Arrangement of charges and hard-steel rings in the *YIMpact* system. (*Cairns and Hardwick.*[54])



[Courtesy Welding Inst.

37 Aluminium brass tube *YIMpact* welded to Naval brass tube plate. × 6½. (*Cairns and Hardwick.*[54])