et al.,[53] Cairns and Hardwick,[54] Shribman *et al.*,[55] Hardie,[56] and Williams and Crossland.[57] This is a process that may well replace conventional tube-expansion methods for sealing tubes to tube-plate in condensers, heat-exchangers, and boilers by a welded connection. However, in this process it is not possible to achieve a weld right up to the back surface of the tube plate, as this would imply an extremely high impact velocity that would shear the tube or, at best, cause excessive bulging. Consequently, there is the possibility of an interference fit between the tube and tube-plate only towards the back surface of the tube-plate, and the likelihood of fluid getting between the two surfaces and causing crevice corrosion cannot be ignored.

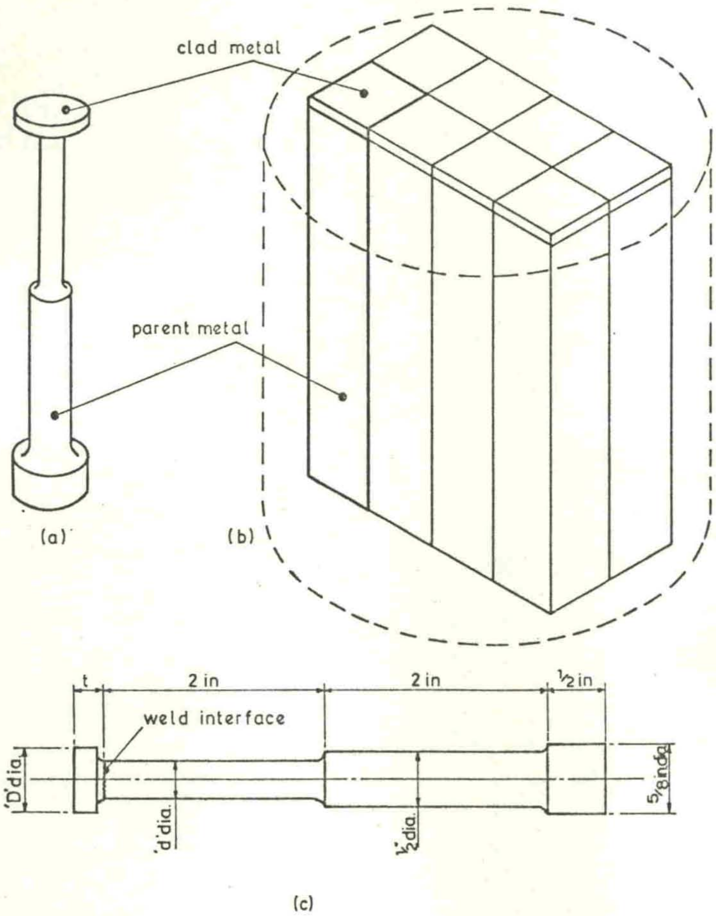
Various methods of tube welding have been developed. If small tubes are to be welded it would obviously be an advantage to be able to use a detonator, but most detonators contain a high-detonation-velocity explosive (see Bahrani and Crossland[58]) and consequently an inclined technique has to be employed. Four possible inclined-angle techniques have been suggested[53] and the most important of these is illustrated in Fig. 34. The first of these three methods, which requires a tapered hole in the tube-plate, has been patented by Yorkshire Imperial Metals, Ltd., under the trade name *YIMpact** and is described by Cairns and Hardwick.[54] The schematic arrangement of the *YIMpact* process is as given in Fig. 35. It will be seen that the tube stands proud of the front face of the tube plate and the explosive charge can be positioned by means of the legs moulded into the plastic insert, which acts as a buffer. The excess length of tube is sheared off in the process to form a tube end which is flush with the front face of the tube plate, and this also ensures that a weld is obtained close up to the front surface. The excess tube removed in the process, or even debris of the plastic insert, can damage adjacent tubes that have not been welded, or even catch the lip of tubes that have been welded, according to Williams and Crossland.[57] However, the former hazard can be avoided by hardened steel rings which are a slip fit over the protruding tube, as shown in Fig. 36, and the latter is not experienced in the *YIMpact* process if the recommended conditions are adhered to. In this process a typically wavy interface is obtained, as shown in Fig. 37.

* Patent applications 34 537/65 and 39 172/65.

Various combinations of alloys can be welded by the *YIMpact* process but with a detonator alone the size of tube is limited by the charge size in the detonator. However, the charge can be supplemented by additional explosive and this allows a wide range of tube sizes to be welded. With some alloys and sizes unfavourable residual hoop stress may be present in the tube close to the front surface. These stresses can be eliminated simply and rapidly by peening the tube ends.

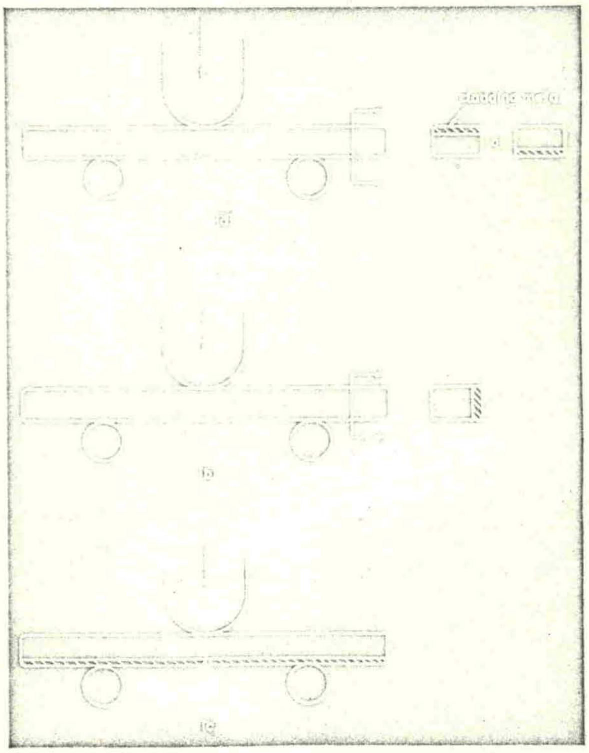
Crossland *et al.*,[52] carried out experiments with various techniques for tube sizes up to $2\frac{1}{4}$ in (57 mm) O.D. × $\frac{1}{8}$ in (3·2 mm) wall thickness. With the tapered technique the weld quality along the taper was far from uniform. They attributed this to the reduction in impact velocity close to the front surface of the tube due to the increased energy absorbed in expanding the tube and to the increased clearance. It was also felt that the tapered hole would raise the manufacturing cost and increase the minimum ligament thickness.

Crossland *et al.* suggested the parallel-welding technique shown in Fig. 38; this requires a two-diameter hole which is



29 Tension test normal to weld interface.

t in	*t* mm	*d* in	*d* mm	*D* in	*D* mm
1/16	1·6	$\frac{1}{4}$	6	$\frac{1}{2}$	12·7
$\frac{1}{8}$	3·2	$\frac{3}{8}$	9·5	$\frac{5}{8}$	15·9



30 Bend tests.

(a) Normal bend;

(b) side bend:

(c) notched bend.