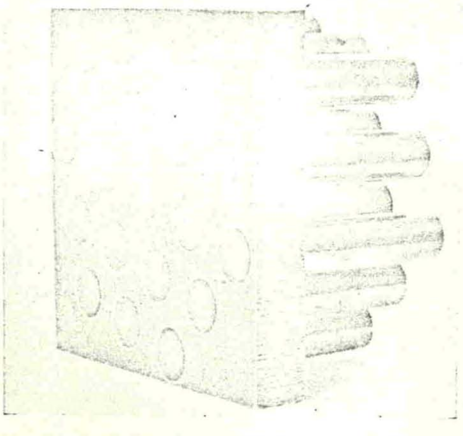


40 A group of hard-drawn, thin-walled copper tubes welded in a brass tube plate.

tension test indicated that the bond between the tungsten wire and the copper plates was fairly good. By positioning multiple layers of alternate wires and foils a composite (Fig. 49) was produced which had a final volume fraction of wire of 17%. The wire diameter was 0·006 in (0·15 mm) and the copper-foil thickness 0·012 in (0·30 mm). The multilayer composite gave a tensile strength which could have been predicted from the strength of the two starting materials. The explosive production of fibre-reinforced materials gives promise of some very interesting developments.

V. Metallurgy of explosive welding

1. General observations

At the end of Section I it was noted that there are three main types of interface in explosive welds. For large angles of obliquity, i.e. $\sim 15°$, the re-entrant jet that is formed from the two surface layers completely escapes, and this leads to a solid-phase bond as illustrated in Fig. 13. This shows the localised plastic flow which occurs and it will be noted that it is not consistent with the suggestion of relative sliding proposed by Otto.[14]

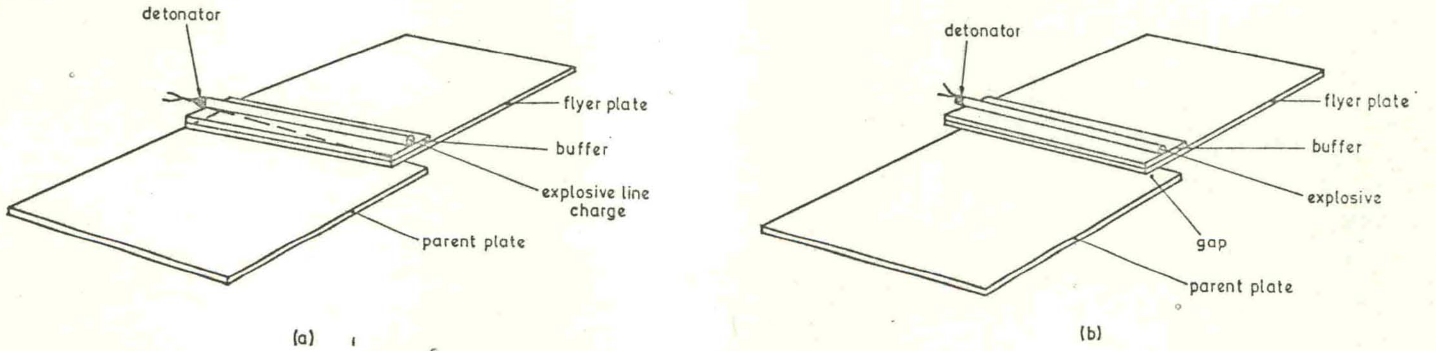
More usually, smaller collision angles, i.e. $< 5°$, are employed, especially in the parallel-plate technique, and under these conditions the jet is trapped as explained by the mechanism of Bahrani *et al.*[25] illustrated in Fig. 17. In Fig. 15 it can be seen that the interface of such a weld consists of alternate regions of solid-phase bonding and fusion-bonded pockets. The grain size in the fusion pockets may be of the order of 1 μm and optical microscopy is therefore unable to resolve the detail in these regions as shown in Fig. 14. However, by means of electron microscopy of carbon replicas from the vortex regions (Fig. 50) Lucas *et al.*[28] have found clear evidence of melting in the vortex area in all the welds examined, including tungsten-to-tungsten with a melting point of 3400° C (3673 K).

Under extreme conditions it is possible to produce a weld interface consisting entirely of fusion bonding (Fig. 16), which according to the mechanism proposed by Bahrani *et al.* is due to the linking up of the molten pockets.

In addition to the features observed at the weld interface, it is clear that metallurgical changes are effected in the two component members by the intense stress waves generated both by the detonation of the explosive layer and the high-velocity collision during welding. Severe mechanical twinning and phase changes in the shock-affected zones on each side of the weld interface have been reported. Spall fractures which occur away from the interface have also been recorded.

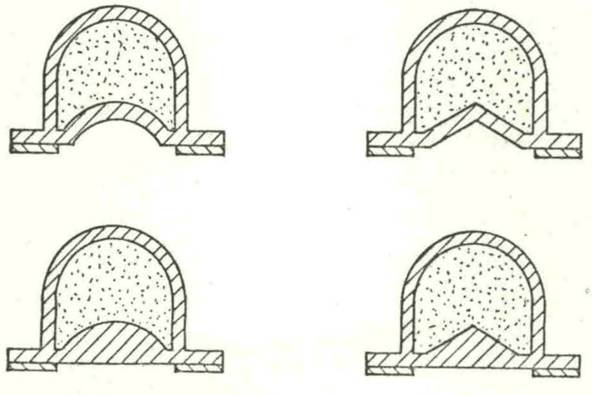
2. Solid-phase bonded interface

As can be seen from Fig. 13, the high impact pressure and jetting action have caused considerable plastic flow at the interface. Electron micrographs of carbon replicas taken from this type of bond have been published by Holtzman and Cowan,[21] Buck and Hornbogen,[64,65] Trueb,[66] and Lucas *et al.*[28] A typical example is shown in Fig. 51, from which it can be seen that the original interface is no longer distinguishable. The bond zone is a band, $\sim 10^{-3}$ cm thick, composed of several layers of highly elongated grains, $\sim 10^{-4}$ cm thick, and no evidence of original surface-oxide films remains. Annealing of this type of weld interface allows complete recrystal-

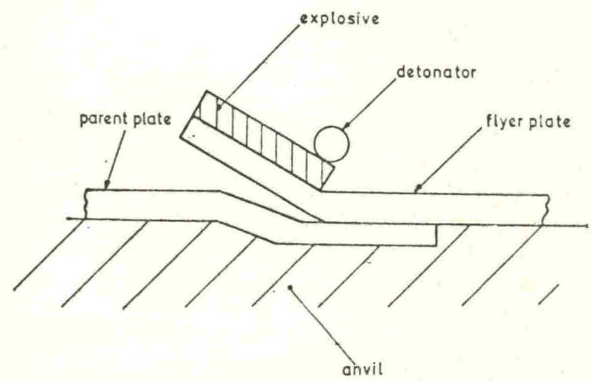


[Courtesy 'Welding'

41 Welding of lap joints, (a) Inclined technique; (b) parallel technique. (*Addison, Kogya, and Kaisha.*[61])



42 Line charge shapes.



43 Welding of lap joints. (*Polhemus.*[62])