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SOME FEATURES OF THE FABRICATION OF MULTILAYER FIBER COMPOSITES BY EXPLOSIVE WELDING

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16. Abstract

The fabrication of multilayer fiber composites by explosive welding is characterized by intense plastic deformation of the matrix material as it fills the spaces between fibers and by high velocity of the collision between matrix layers due to acceleration in the channels between fibers. The plastic deformation of the matrix layers and fiber-matrix friction provide mechanical and thermal activation of the contact surfaces, which contributes to the formation of a bond. An important feature of the process is that the fiber-matrix adhesion strength can be varied over a wide range by varying the parameters of impulsive loading.

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SOME FEATURES OF THE FABRICATION OF MULTILAYER FIBER COMPOSITES BY EXPLOSIVE WELDING

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Explosion welding has found increasing use in recent years as a method of bonding different materials in the production of metal sandwich composite and fiber composite materials (MSC and FCM). The process flow diagrams, conditions for performing explosion welding of sandwich composites, and features of layer bonding during explosion welding of MSC are detailed in many works ([5], for example). The specifics of the FCM manufacturing process with explosion welding, however, have so far been studied to a lesser extent. /80*

The specific structure of the FCM blank undergoing welding (the presence of numerous fibers in the zone of matrix layer impact) and certain requirements associated with the subsequent mechanical behavior of FCM when loads are applied (in particular, the requirement that there be no extraordinary local matrix fusion, and virtually no waves in the bonding zone) define many features of the process of FCM explosion welding relative to explosion manufacture of MSC.

One characteristic determined by the presence of numerous rigid reinforcing fibers in the matrix layer contact zone is intense plastic deformation of the matrix material when it flows into the gaps between the fibers, which consist of channels of shrinking cross-section [6], and marked increase in the impact speed of the matrix layer surfaces because of matrix acceleration as it moves in these gaps [7]. If the impact front propagates along the reinforcing fibers, the latter of these circumstances produces a corresponding increase in impact angle of the matric layers in the gaps between the fibers [7]. Plastic deformation of the matrix-layer surfaces when they flow between the fibers (the greater it is, the smaller the spacing of the fibers) and friction in the fiber-matrix zones when fibers are introduced into the

*Numbers in the margin indicate pagination in the foreign text.

matrix ensure prior mechanical and thermal activation of the layers being welded, thus facilitating the formation of their bond.

Furthermore, when the reinforcing fibers are packed densely /81 enough, explosion welding of FCM becomes possible with a transition to substantially supersonic conditions, including at a contact-point speed $V_c \to \infty$ (i.e., welding becomes possible under flat projection conditions as well); in the latter case, and also when the impact front propagates at right angles to the fibers, a weld is formed if the surfaces of the matrix layers collide much below the mid-point of the reinforcing fibers. The possibility of obtaining FCM under any supersonic conditions, including with flat projection, is perhaps the most interesting feature of FCM explosion welding. This feature, first established in [7], is also noted by the authors of [8].

Another important feature of the process of manufacturing FCM with explosion welding is the possibility of obtaining fiber composites with different fiber-matrix-adhesion resistance to direct pull, σ_{m-f}, within a rather wide range of values (to as much as σ_{m-f} values close to the matrix strength σ_m) through varying the technological parameters of impact loading [8], which is characteristic only of explosion welding and one of its chief advantages over other familiar methods of manufacturing FCM. The mechanism of σ_{m-f} change in the case of steel-aluminum FCM is regulating the amount of local matrix fusion in areas of matrix contact with fibers [8].

In practice, when manufacturing multi-layer FCM with explosion welding it is expedient to employ an "unwelded" massive metal plate (MMP), which is merely an energy carrier that creates a high-momentum impact on the FCM blank being welded [5]. On the one hand, the use of MMP helps a great deal to regulate the energy expended in each single impact of the layers, and thereby helps control the amount of local matrix fusion in the areas around the fibers, which usually occurs in FCM welded by explosion [9]; on the other hand, it helps produce a more even distribution of energy through the layers. This /82 is directly implied by analysis of the explosion-welding energybalance component losses in plastic deformation $\Delta W = 1/2\ [m_1 v_1^2 \cdot m_2/(m_1 + m_2)]$ (here m_1 is the unit mass of the MMP); v_1 is its speed; m_2 is the unit mass of the matrix plate) [3] and the law of conservation of momentum. In addition, the use of MMP helps practically eliminate waves when welding a multi-layer stack[1], which follows from [11], in which an examination of wave-formation theory makes a theoretical prediction of and experimentally proves the relation between wavelength and the experiment's parameters, in the form

$$\lambda = 34 m_1 \frac{m_2}{m_1 + m_2} \sin^2(\gamma/2)$$

(Here γ is the MMP impact angle). This relation, as well as the expression for ΔW, contains ratio $m_2/(m_1 + m_2)$. Clearly, increasing the MMP mass when welding a stack of FCM containing thin matrix layers ($m_2 << m_1$) severely diminishes wave size, i.e., the use of MMP when manufacturing multi-layer FCM with explosion welding can be considered a specific feature of this process.

When limiting (eliminating) wave formation in the process of explosion welding of multi-layer materials in general, and FCM in particular, one other feature, established in [12, 13], should also be borne in mind. These works pointed out that a certain time, $t_w \simeq 0.6$-1 μsec, is needed for complete development and "setting" of the pattern of waves generated during the impact. If the impact conditions change substantially during the time interval $(0, t_w)$ (for instance, the stack being welded strikes a new layer), the wave sizes also change (the waves become larger) in accord with these impact conditions (a new mass ratio). So the presence of a characteristic setting time t_w for the wave pattern imposes certain restrictions on the minimum size of the gaps between the layers being welded. The time before collision with the next layers, t_3, should be no less than the time of development and setting of the wave at the given bond boundary, i.e., condition $t_w \leq t_3$ must be met, from which it is /83

[1] Discussion of possible wave formation during explosion welding of FCM makes sense in the case of sparse enough packing of the reinforcement.

easy to determine the required size of the gap between layers.[2]

Consideration of these features when manufacturing FCM with explosion welding produces high-quality fiber composites. For example, the use of explosion welding by one of this work's authors to manufacture steel-aluminum FCM made it possible to obtain a spectrum of FCM with σ_{m-f} values from 0 to $(0.7-0.8)\sigma_m$ (the τ_{m-f} varying between 0.5 and $1\tau_m$) with virtually no perceptible damage to the fibers or matrix [9, 14].

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[2]As indicated by evaluation of the time of fiber introduction into the matrix layers [7], when explosion welding FCM with fiber diameters $d \geq 0.3$ mm the condition $t_w \leq t_3$ is met, as a rule.

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