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THE STATE OF TWO-METAL CONTACT BOUNDARY AT HIGH-VELOCITY IMPACT

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Abstract. *The character of disturbance development on a contact boundary of metals layers at a constant impact angle (γ), but at a varying velocity (v_c) of a contact point was investigated. Velocity v_c growth in a subsonic regime leads to a loading pressure and elastic shear deformation intensity increase. Disturbance amplitude grows. At critical velocity v_c values for individual metal pair, characterizing a transition from subsonic to supersonic flow, when disturbance amplitude reaches maximum. An analytical relation for disturbance amplitude on contact boundaries of different metal pairs and their strength properties was proposed.*

INTRODUCTION

In dynamic investigations of solid under high pressures two loading types are usually used - normal or oblique shock wave. In contrary to the case of normal shock wave loading, the description of elastic and wave processes under an oblique shock wave is complicated by the necessity of normal as well as tangential components account in stress tensor [1].

Under an oblique impact of metal layers in a contact zone, intensive shearing deformations develop, preboundary layers of materials become strongly heated, cumulative jets might occur. The effects mentioned result in profile deterioration of metal contact boundary after an impact. Regular disturbances (waves), non-symmetric disturbances (distorted waves), melting layers of mixed component originate. In certain cases such disturbances' development result in firm bonding of samples, i.e. explosion welding [2].

In special literature a subsonic regime of an oblique impact ($v_c < c_o$), is investigated in detail (here v_c is a contact point velocity, and c_o is sound velocity in given metal). Under such loading conditions a cumulative jet is constantly formed in a contact point [2-4]. Well investigated is a coupling of disturbance development character on a contact boundary with the parameters, defining the loading conditions: thickness and material of impacting plates

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(δ, ρ), thickness and composition of high explosive (δ_{HE} , ρ_{HE}), collision angle (γ) and so on [2-4].

Sample collision at a velocities, exceeding a sound velocity ($v_c > c_o$), is described in analogy with the description of supersonic flux, flowing over a wedge [1]. For a constant collision angle ($\gamma = const$) a critical value of a contact point velocity v_{cr} exists. At $c_o \le v_c \le v_{cr}$, detached shock waves are formed in a flux. Crossing a shock wave front, the supersonic flux transforms into a subsonic one. To a constant point both fluxes (a flying and a fixed plates in a coordinate system, connected with a contact point) come at a sound velocity, in a collision zone cumulative jet is formed. At $v_c > v_{cr}$, attached shock waves are established in a contact point. They turn the fluxes at an angle, approximately equal to a collision angle. A jet formation is impossible in such a regime, and a explosion welding as well [1,2]. A contact boundary state of the materials under such supersonic oblique impacts is not investigated practically.

EXPERIMENTS AND RESULTS

The present paper is devoted to the experimental investigation of contact boundary state of metal layers under various regimes of oblique impacts (contact point velocities v_c), but at a constant loading angle γ. In the tests a traditional scheme of plate casting was used in the regime of HE charge sliding detonation (Fig. 1).

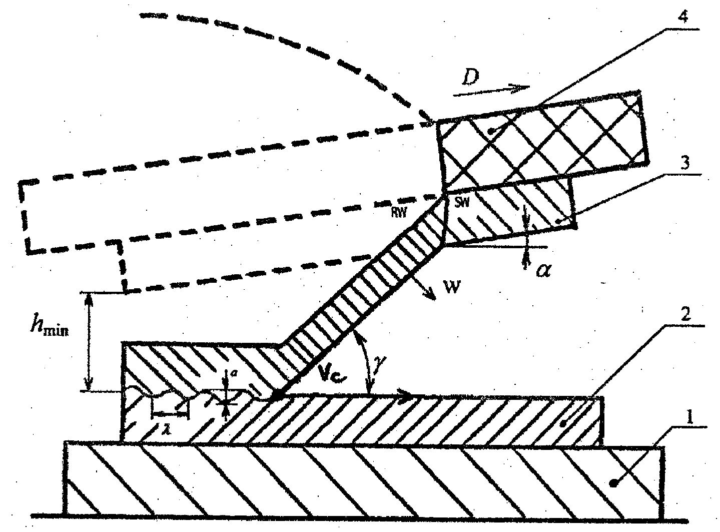

Fig. 1. Test arrangement scheme

A fixed plate (2) is mounted on a massive steel base (1). At a given angle α, a casting plate (3) is mounted, accelerated by explosion products of HE (high explosive) charge (4), where a plane sliding detonation wave is realized. Minimal distance between the plates (h_{min}) is selected, minding the stationarity of a striker flight before the impact [5].

$$h_{min} \geq (3-5)\delta_{st}\,, \tag{1}$$

where: h_{min} - minimal distance between the plates; δ_{st} - a striker thickness;
D - detonation velocity of HE charge; w - striker flight velocity;
v_c - a contact point velocity; α - an initial angle of plates' tilting;
γ - an angle of plates' impact; SW - shock wave front;
RW - head characteristic of a rarefraction wave;
a, λ - amplitude and length of realizing disturbance wave.

It is known that at contact point velocities $v_c < 1{,}5$ mm /μs, on a separation boundary of two arbitrary metals the disturbances are not formed. In this case loading pressure P_c is not great. Material strength impedes shear strain strams realization. At $v_c > 1{,}5$ mm/μs, on a contact boundary, symmetric wavy disturbances occur. With a subsequent velocity v_c growth, the waves lose symmetry, the crests become eddy, the disturbance amplitude increases a bit.

When analyzing the experimental data, we have chosen as the main parameter, characterizing the state of a contact boundary - the amplitude of realizing disturbances (a). Disturbance amplitude was assumed to be a perpendicular distance from a crest peak level up to an ultimate depression of adjacent valley (when wave formation is evident); or a perpendicular distance between the levels of adjacent heaping and valley (if disturbances dramatically differ from regular waves); or the whole width of turbulent mixing zone of contacting materials. In the analysis of experimental data as a disturbance amplitude, an averaged value was accounted after ~ 20 adjacent disturbance were calculated.

In Fig. 2 disturbance amplitude dependences at contact boundaries of individual metal pairs on Mach number ($M = v_c / c_0$) are presented. We have chosen M - variable to graphically interpret the experimental data, basing on the similarity for comparison of disturbance amplitudes on contact boundaries of different metals under identical loading conditions.

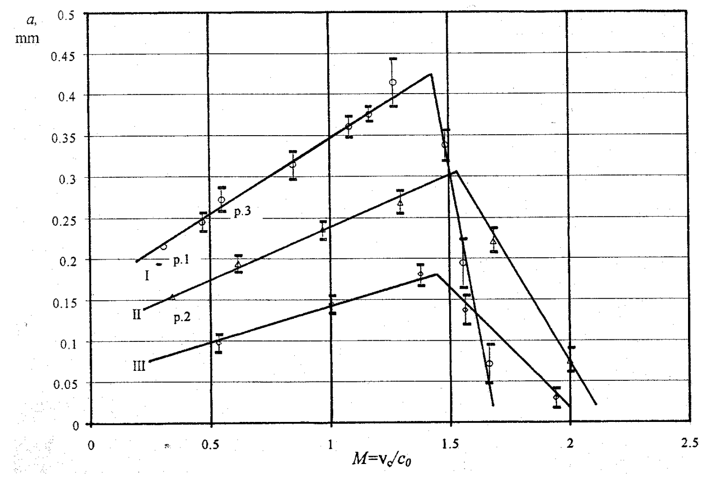

Fig. 2. Amplitude of perturbations on contact boundaries between metals layers versus Mach number: I - AlMgZn alloy - AlMgZn alloy; II - Copper - copper: III - Steel St.3 - steel St.3

In Fig. 3 a realizing flux pattern near an impact zone in a coordinate system, coupled with a contact point is presented.

Velocity v_c growth results in the increase of loading pressure and elastic shearing deformation intensity in the contact zone. The greater mass of metals is entrapped into a jet flux. The disturbance amplitude increases.

On the three metals investigated, aluminium is the most usable. So its melting is explained at a wave formation, which is strengthened with v_c velocity growth and which is finished by a complete mixing of melted layers on a contact boundary. For copper this effect is weaker expressed, however zones are seen, which are enveloped by the intensive melting. For steel an intensive warming up was not reached in rather wide pre - boundary areas. However, a state, resembling melting, is denoted in the narrow layers near a contact boundary.

When each metal pair has an individual critical velocity values v_{cr} which characterize the transition from subsonic flow to a supersonic zone, the disturbance amplitude reaches maximum. A further velocity v_c growth is accompanied by an impacting plates' turn. A jet formation in a contact point is absent (supersonic flux is illustrated in Fig. 4).

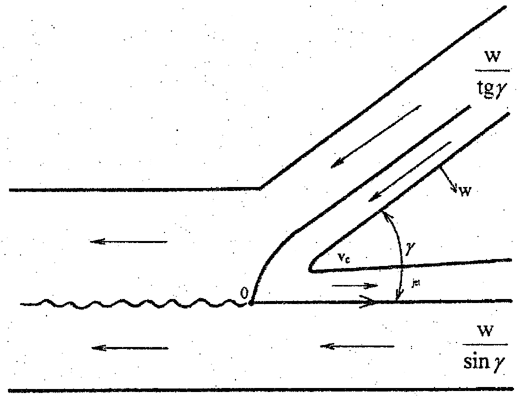

Fig. 3. Scheme of flow realized near the collision zone,
coupled with the contact point, in regime subsonic oblique collision

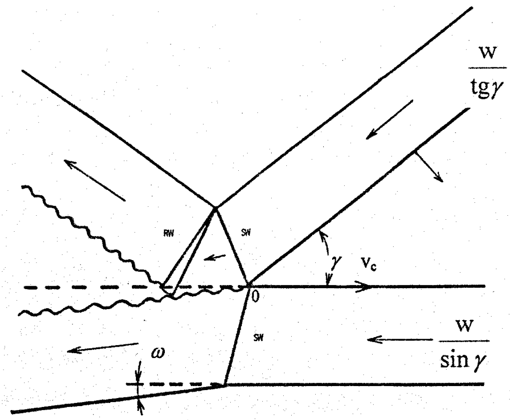

Fig. 4. Scheme of flow realized near the collision zone in regime
of supersonic oblique collision with attached shock waves

In such regime on the contact boundary disturbances are formed under Kelvin - Helmholtz instability development. The plates' turn takes place at a rarefraction wave output on the contact boundary. Contact time of metal layers may be approximately defined as :

$$t = \frac{\delta_{st}}{D_s} + \frac{\delta_{st}}{c_0} \quad (2)$$

where: δ_{st} - a striker thickness,
c_o - sound velocity in a given material,
D_s - a shock wave velocity in a plate material.

The conservation law on an oblique shock wave front testifies that a similar plate impact is accompanied by their turn at an angle ω [4]. Before separation during t period two fluxes move behind the fronts of oblique shock waves in parallel, touching one another. Their relative sliding takes place. At a wave front a sample temperature rises. In the relative sliding the intensive shearing deformations are realized on the contact boundary; Kelvin - Helmholtz instability is developed, which results in disturbance formation on a separation boundary between two metals. Contact plane melts, that lead to an explosion welding in the thin pre - boundary layers. A rarefraction wave, separating the plates, tears a welded joint. A certain part of a striker metal remains attached to a fixed plate surface in the form of a porous layer. With velocity v_c growth, a velocity of a relative metal sliding increases as well; simultaneity only, their contact time reduces. The disturbances fail to form completely, their amplitude decreases.

The test results show, that a disturbance amplitude is higher for the metals with lower strength characteristics.

At a high - velocity oblique impact the metal behavior in the vicinity of a contact point is satisfactorily described from the hydrodynamic point of view [2-4, 7, 8]. In fact, thin pre - boundary metal layers some microns thick transform into a liquid phase. The metal mass remained near a contact point transforms into a somewhat elastic quasiliquid state, which behavior greatly depends on a shear stress magnitude (τ) that can be estimated as a half - difference between a normal stress (P_n) and a stress tangential (P_τ) to a shock wave front [9]:

$$\tau = \frac{P_n - P\tau}{2} \quad (3)$$

On the other hand, there is a relation for a dynamic strength yield (Y), which characterizes ability of a material to resist shear deformations [9]:

$$Y = 2\tau \quad (4)$$

In work [4] in the analysis oh the geometry of metal layers' contact boundaries after an oblique impact the authors showed that a realizing disturbance amplitude is proportional to an equivalent Reynolds number:

$$a \sim R_e = \frac{(\rho_{st} + \rho_{pl})v_c^2}{2(H_{st} + H_{pl})} \quad (5)$$

where: a - disturbance amplitude, R_e - equivalent Reynolds number,
v_c - contact point velocity, ρ_{st} , ρ_{pl} - densities of a striker and a fixed plate,
H_{st} , H_{pl} - microhardness of a striker and a fixed plate.

Rewriting this relation for a case of similar plates' impact and accounting for correspondence of a dynamic yield strength to the physical processes to an even greater degree which occur on an contact boundary, than the microhardness H, introducing the relation $M = v_c / c_o$ and minding that product of $\rho_{pl}\, v_c\, c_0$ is, in fact a pressure parameter in the vicinity of a contact point P_c , we obtain:

$$a \sim R_e = \frac{P_c M}{Y} \tag{6}$$

where: P_c - pressure in contact point, M - Mach number, Y - dynamic strength yield.

When the disturbance amplitudes on the contact boundaries of different metals' layers are compared, Mach number M becomes fixed and a loading pressure P_c for it - as well. A particular value Y corresponds to each P_c magnitude. Thus, the relation (6) transforms into a simple interaction of two parameters:

$$a \sim \frac{1}{Y} \tag{7}$$

That is, the smaller is the value of the dynamic strength yield of the given material, the bigger is the disturbance amplitude on a contact boundary and vice versa.

The connection between a disturbance amplitude on a contact boundary and a dynamic strength yield for copper and steel remains in a supersonic loading regime as well. In this case the wave material properties are dominant. The preliminary results on the relation between the disturbance amplitude on contact boundaries of various metal pairs are obtained as well. An analytical expression for this relation has a more complex character.

CONCLUSIONS

Thus, the results presented enable us to build a function of a disturbance amplitude on a contact boundary of metal layers on Mach number in wide range of a contact point velocities. An analytical connection of the disturbance on contact boundaries of different metal pairs with their strength properties (dynamic strength yield) is expected. Oblique collision of metal layers with supersonic and hypersonic velocities v_c of the contact point was studied experimentally for the first time. Perturbations growth was recorded on the metals interface boundary in regime with oblique shock waves, joining the contact point. Results of this work allow to extend understanding of the problem of high - velocity oblique impact and predict state of the collided surfaces.

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STANJE KONTAKTNE GRANICE DVA METALA NA VELIKIM BRZINAMA

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U radu je istraživan karakter razvoja poremećaja na kontaktnoj granici metalnih slojeva pri konstantnom napadnom uglu (γ) pri promenljivoj brzini (v_c) u jednoj tački kontakta. Porast brzine v_c do subsoničnog režima dovodi do porasta pritiska opterećenja i veličine elastične smičuće deformacije. Amplituda poremećaja raste. Kritična brzina v_c za određeni par metala karakteriše prelaz sa subsoničnog na supersonično strujanje koda poremećajna amplituda dostiže maksimum. Predložena je analitička relacija za amplitudu poremećaja na kontaktnim površinama različitih parova metala različitih svojstava čvrstoće.