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Impact Atom Emission

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Abstract

It is shown, that if a steel plate is subjected to a projectile impact, the atomic emission is induced from the great amount of craters that appear on the plate's side opposite to the place of impact application. The craters' mean size and shape are same to cathode craters in a low-voltage vacuum arc. This similarity shows that the reasons of mechanical and electrical failure of metals can be identical in either case.

Keywords: metal impact, electron inertia, atomic emission

1. Introduction

Crystal lattice solidity in metal is secured by metal cohesion energy $\boldsymbol{\varepsilon}$ between quasi free electrons and positive charges of nuclei localized in points of lattice. The lattice exists until "not much" (Kittel, 2005) imbalance energy $\boldsymbol{\varepsilon_d}$ spoils an energetic balance between these particles. In (Marakhtanov & Marakhtanov, 2000) it is shown that "not much" energy $\boldsymbol{\varepsilon_d}$ = 0.051; 0.028; and 0.004 eV/atom is sufficient for blowing cold Al, Ti and W, respectively, while the cohesion energy of these metals is more higher, and is $\boldsymbol{\varepsilon}$ = 3.34; 4.85; and 8.66 eV/atom, respectively.

It is known that the force of inertia shifts free electrons relatively points of lattice that causes the following effects. If a rotating coil is stopped with negative acceleration – (100…500) m/s^2, the electron current appears in its wire (Tolman, Stewart, 1916). If the lead bullet blows with acceleration of – $4.3 \cdot 10^6$ m/s^2, the external antenna fixes an electron impulse that appears in the lead (Marakhtanov & Marakhtanov, 2013). Acceleration of – $(2…4.3) \cdot 10^7$ m/s^2 is sufficient for evaporating the metallic projectile (Marakhtanov, 2009).

In the present work it is shown that the metallic projectile of 30 mm in diameter induces atom emission from a steel target, if the projectile impact acceleration is – $(3.6…5.5) \cdot 10^6$ m/s^2. The information on revealed effect can be used for developing ways for protecting metallic samples against shock failure.

2. Experiment

We are able to show experimentally that the lead projectile *1* can induce atom emission from the steel target during impact (Fig. 1). A target-plate is made of rolled steel of 35 mm in thickness (the iron content is 85,4 %). The projectile presents itself a steel cup of 30 mm in diameter and of 48 mm in length filled partially with lead. Projectile's mass is M = 0.266 kg, lead mass is 0.099 kg. The projectile moves towards the target by a lead-filled side. Projectile's velocity is v = 898±12 m/s, kinetic energy is W = 107250±2800 J. The rate of motion of all elements is determined according to image shift in video frames recorded by camera Phantom V 16 model 10. The exposure time for one frame is 10^{-6} s, period T = 1/51000 s. External lighting of the target secures through translucence of vapor emission products.

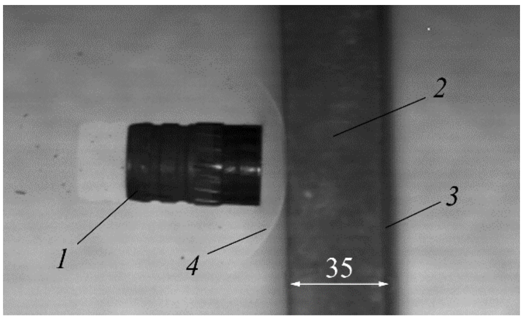
From Figure 2 it is seen that the projectile expels practically a cylindrical plug *1* from the target (plug's mean diameter is 47 mm). A segment *3* filled with transparent vapor-like mixture *4* moves ahead the plug. Segment's outline *3* appears in frame №3 as a small surface bulging of not deformed target. This moment we accept as an atom emission beginning. The end of emission corresponds to frame №20, when new steam jets *5* do not appear at plug's front. We accept that emission duration is equal to the period between these frames: $t \approx$ (№20 – №3) / 51000 = $3.33 \cdot 10^{-4}$ s. For the period of time between exposure of frames №13 and №17, the mean velocity of plug's center of mass is v_1 = 54.3 m/s, the velocity of emission flow boundary is v_3 = 186.6 m/s.

The frontal surface of the plug transforms into a porous structure due to impact. Its 3D images are recorded with laser scanning confocal microscope (Carl Zeiss LSM 700). It is seen that the frontal surface of the plug, which in the initial state has microscopic threadlike tracks caused by rolling, are totally covered by small craters (Figure 3).

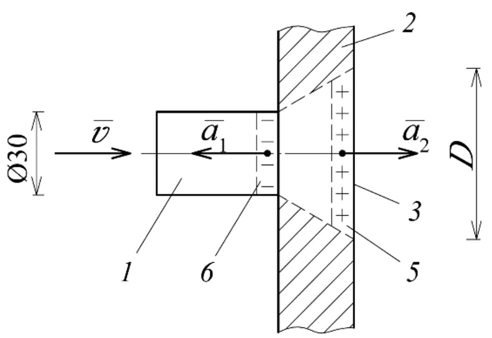
The mean number of craters per unit of surface area is $z \approx 8$ piece/mm^2. The sizes of "mean" crater are as follows: diameter is 120 µm, depth is 45 µm, cross section area is $s = 0.011$ mm^2, and volume is $V = 5\cdot10^{-13}$ m^3. The area of plug's frontal surface is close to the circle area with diameter of 47 mm and it is F = 1735 mm^2. There are approximately $b = zF \approx 1.4\cdot10^4$ craters with total area of $S = sb$ = 154 mm^2 on it.

3. Results and Discussion

Due to the impact the quasi free electrons move inertially and form an excess electric charge with respect to bond points of lattice (Figure 1). Projectile's lattice decelerates with acceleration $-a_1$ and electrons being ahead of lattice points generate excess negative charge in area *6* (Figure 1, b). On the other hand due to the impact the target surface moves with acceleration $+a_2$ as a whole with target's lattice. Due to inertia the free electrons are behind the target lattice and area *5* is characterized by excess positive charge (Fig. 1, b). Both forms of excessive charges cause Coulomb explosion of the lattice and as a result the metal destroys. The Coulomb explosion of the projectile is described in (Duhopel'nikov *et al.*, 2010), but a phenomenon of craters formation on the target (Figure 3) we observe for the first time.

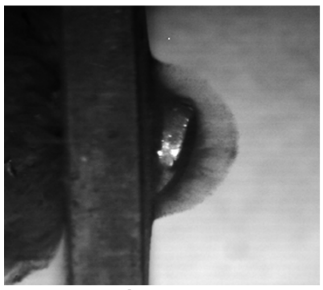


a, frame №0

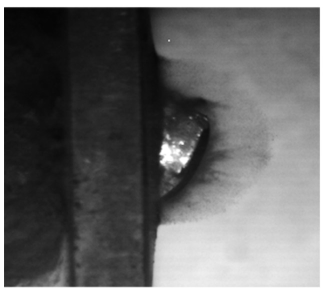


b

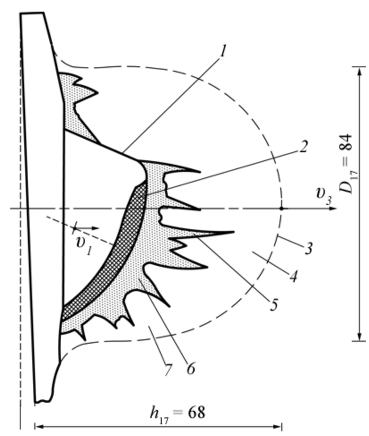
Figure 1. Video (frame № 0) made exactly before the projectile and target collision (*a*); diagram of inertial displacement of electric charges in the projectile and the target (*b*): *1* — projectile; *2*— target-plate; *3* — the target emission surface; *4* — the front of shock wave in air; *5* — excess positive charge zone; *6* — excess negative charge zone; *D* — diameter of emission surface; $\bar{a}_1$ — projectile deceleration; $\bar{a}_2$ — acceleration of the emission surface; $\bar{v}$ = 898 ± 12 m/s — velocity of projectile before impact



a, frame №13



b, frame №13



c, diagram of the frame №17

Figure 2. Motion of expelled plug (*a*, *b*), and the diagram of emission segment; *1* — plug's cylindrical surface; *2* — plug's frontal surface; *3* — frontal boundary of emissive flow; *4* — volume of emission products; *5* — vapor jet; *6* — dense flow; *7* — rare flow; υ_1 — velocity of the plug's center of mass; υ_3 — velocity of the emission flow boundary

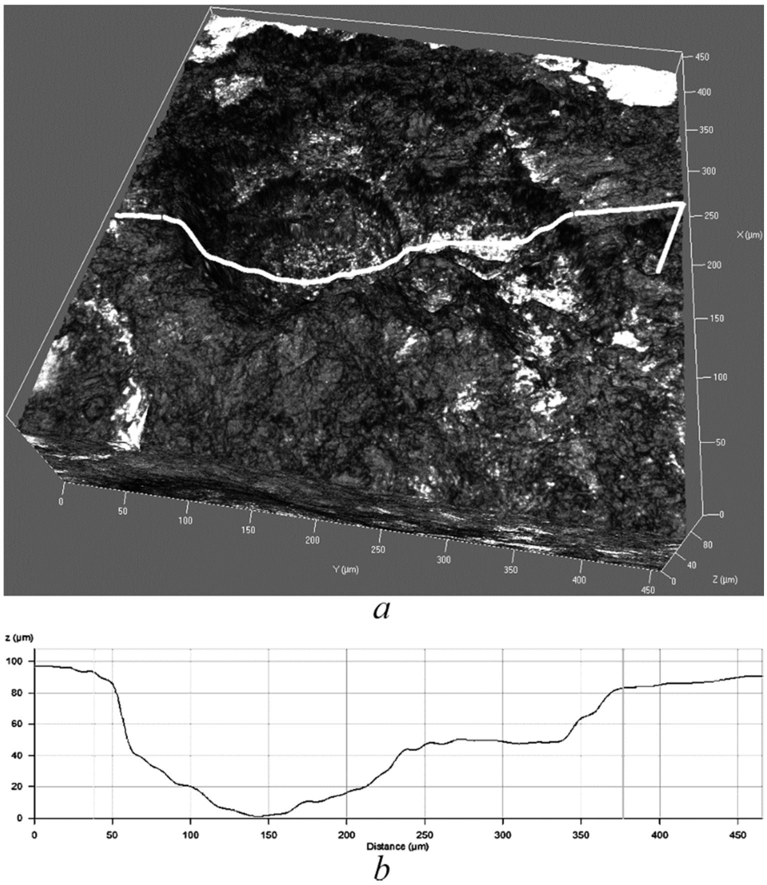


Figure 3. Typical crater on plug's frontal surface (*a*), and its cross-section (*b*); crater's diameter in cylindrical part is about of 180 µm; the greatest depth of the crater is about of 100 µm

Let us assume that the target is made of iron (in reality the share of Fe is 85.4%, as state above). In this case the number of Fe atoms emitted by mean crater is

$$N = \frac{\rho V}{Am_p} = \frac{7874 \cdot 5 \cdot 10^{-13}}{56 \cdot 1{,}67 \cdot 10^{-27}} = 4{,}2 \cdot 10^{16}, \quad (1)$$

where $\rho = 7874$ kg/m^3 is a density and $A = 56$ atom units of mass is the atom mass for iron. The energy needed for evaporating (in our case we call it *the impact atom emission)* these atoms can be written as follows

$$\Sigma = \varepsilon N \approx 4{,}29 \cdot 4{,}2 \cdot 10^{16} \approx 1{,}8 \cdot 10^{17} \text{ eV} = 0{,}029 \text{ J}, \quad (2)$$

where $\varepsilon = 4.29$ eV/atom is cohesion energy for iron (Kittel, 2005). The energy

$$E = b\Sigma = 1{,}4 \cdot 10^{4} \cdot 0{,}029 = 406 \text{ J}, \quad (3)$$

is required for metal emission from all craters that appear on the frontal surface of the plug. And it is only 0.4% of projectile's kinetic energy $W = 107250$ J.

Let us assume that each atom that leaves crater carries an elementary charge *e.* Flow density of such particles is equal to the density of equivalent electric current

$$j_{eq} = \frac{eNb}{tS} = \frac{1{,}6 \cdot 10^{-19} 4{,}2 \cdot 10^{16} 1{,}4 \cdot 10^{4}}{3{,}33 \cdot 10^{-4} 154 \cdot 10^{-6}} = 1.8 \cdot 10^{9} \quad \text{A/m}^2, \quad (4)$$

where $t = 3.33 \cdot 10^{-4}$ s is the time of atom emission. Value *t* can be high in spite of the fact that it is connected with free electrons motion in the metal. In (Marakhtanov M.K., & Marakhtanov A.M., pp. 648–651, 2013) it is shown that the same failure of tungsten conductor is continuing even in t = 0.152 s after shutting down the electron flux that causes this effect.

4. Conclusions

If the steel plate is subjected to the projectile impact, the atomic emission is induced from craters that appear on the plate's side opposite to the place of impact application. Projectile's velocity is 898±12 m/s.

The density of particles flow that leave emission crater is $j_{eq} = 1.8 \cdot 10^9$ A/m^2. It agrees with ions flow density $j_c = 0.19 \cdot 10^9 ... 3.61 \cdot 10^9$ A/m^2 for Zn, Al, Ti, Cu and Fe, respectively, which is observed in cathode craters in a low-voltage vacuum arc (Marakhtanov & Marakhtanov, 1998). At the same time consistence z of emissive craters on target's surface, their area s, volume V and shape are similar to cathode craters in a low-voltage vacuum arc (Marakhtanov & Marakhtanov, 1998). The density j_{eq} agrees with current densities $j_c = 1.32 \cdot 10^9 ... 8.04 \cdot 10^9$ A/m^2 that causes electrical explosion in thin films of Sn, W, Ti, Cu, Ni, Al, respectively (Marakhtanov M. & Marakhtanov, 2000). The density j_{eq} agrees also with values $3.4 \cdot 10^9$, $3.2 \cdot 10^9$ and $1.5 \cdot 10^9$ A/m^2, which are observed in experiments with Ag, Cu, and Mo explosive wires, respectively (Webb, Hilton, Levin, & Tollestrup, 1962).

Since parameters of impact emission and parameters of electrical effects (electric arc cathode, electrical explosion of conductors) are similar, we consider that the reason of both phenomena is the same and it is as follows: force balance of Coulomb interaction for oppositely charged particles in metal is disturbed.

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