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CONDITIONS OF SUBMICROCRACKS FORMATION DURING SHOCK-WAVE TREATMENT OF METALS

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Abstract: The formation of submicrocracks located at a quite substantial distance from the source of disturbance, under the action of powerful shock waves has been observed and studied by electron microscopy. The ultimate parameters of the shock waves (pressure, deformation degree) at which the submicrocrack formation is eliminated, have been determined theoretically and confirmed ex-perimentally. Effective means for the prevention of the microfaults formation in the process of ex-plosive hardening treatment of metals have been developed.

Keywords: Hardening, shock waves, submicrocracks, deformation degree, detonation, explosives.

Р. П. Дідик. УМОВИ УТВОРЕННЯ СУБМІКРОТРІЩИН ПРИ ВИБУХОВОМУ ЗМІЦНЕННІ МЕТАЛІВ.

Резюме: За допомогою електронної мікроскопії вивчене утворення субмікротріщин, розташованих на певній відстані від джерела під дією потужної ударної хвилі. Оптимальні параметри ударної хвилі (тиск, ступінь деформації), при яких знижується утворення субмікротріщин, визначені теоретично та підтверджені експериментально. Розроблені ефективні засоби запобігання мікроруйнувань у процесі зміцнення металів вибухом.

Ключові слова: зміцнення, ударні хвилі, субмікротріщини, ступінь деформації, детонація, вибухові речовини.

Р. П. Дидык. УСЛОВИЯ ОБРАЗОВАНИЯ СУБМИКРОТРЕЩИН ПРИ ВЗРЫВНОМ УПРОЧНЕНИИ МЕТАЛЛОВ.

Резюме: С помощью электронной микроскопии изучено образование субмикротрещин, рас-положенных на определенном расстоянии от источника под действием мощной ударной вол-ны. Оптимальные параметры ударной волны (давление, степень деформации), при которых снижается образование субмикротрещин, определены теоретически и подтверждены экспе-риментально. Разработаны эффективные средства предотвращения микроразрушений в про-цессе упрочнения металлов взрывом.

Ключевые слова: упрочнение, ударные волны, субмикротрещины, степень деформации, детонация, взрывчатые вещества.

The use of shock waves in the hardening treatment of metallic articles has found extensive use recently. The substantial achievements in this field resulted from the implementation of extremal physical parameters. However, along with the positive influence of the shock waves on the, properties of metals, adverse effects are observed in some cases, such as opening of the existing microdefects, as well as the formation of new ones. This reduces the durability and operating stability of the articles hardened by explosion. In this case the fact of disturbing the continuity of the material is closely related to the nature of propagation and interaction of the shock waves. Hence, the study of the conditions of the initiation of microcracks by the shock waves and the development of effective means to preclude their formation are of scientific and practical interest.

A characteristic feature of the explosive influence on metals is the wave-like short-time pattern of the load propagation which leads to the localization of stresses, increase in the dislocation density, growth of the strength characteristics. Due to the great diversity in the physic-mechanical properties, structure, chemical composition of metals and alloys there is no general mechanism which could explain the nature of metal hardening under shock waves. Nevertheless, as it is noted in the studies by Kozorezov and Skugorov (1969), Deribas, e.a. (1982), the degree of metal hardening is determined in many cases by the shock wave pressure amplitude, while in some cases it is estimated by the deformation level behind the shock wave front, by the geometry and duration of the applied compression pulse. However, in spite of the difference in approaches, in all cases the hardening degree is determined by the quantity of crystal lattice distortions caused by the passage of the shack wave. This results in an increase of the metal strength parameters with a simultaneous reduction of the plasticity characteristics.

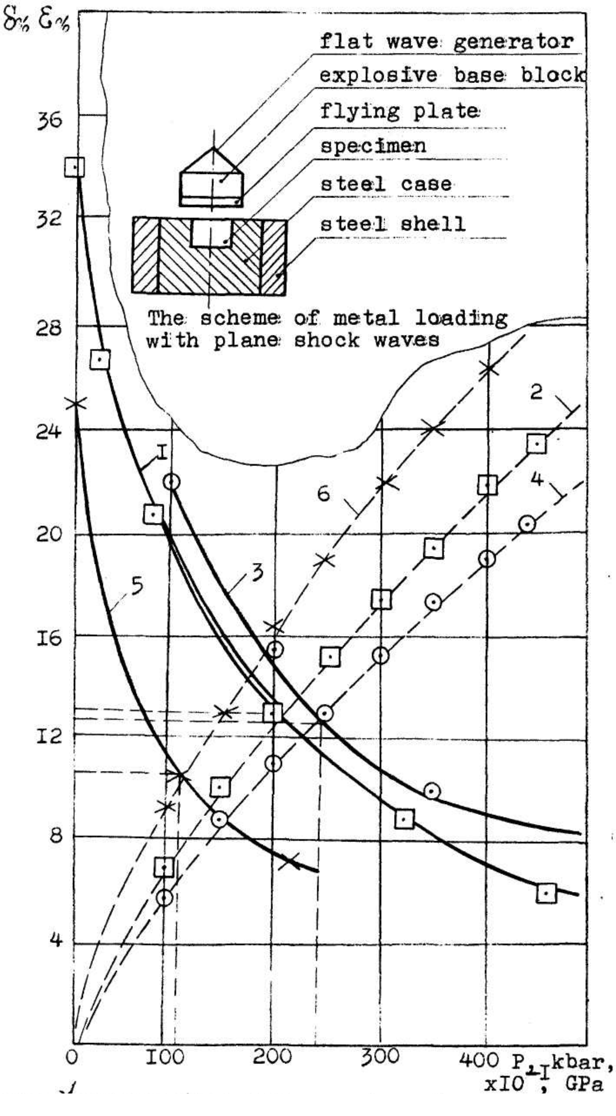

Fig. 1. Deformation-pressure dependence
G-13L: 1 – □ – δ %, 2 – □ – ε %
Ni: 3 – ○ – δ %, 4 – ○ – ε %
St(0.2%C): 5 – X – δ %, 6 – X – ε %
σ_B – ultimate strength; σ_T – yield strength; δ – elongation; ψ – necking; KCV – impact test

Since the aim of the metals hardening is to increase their strength, the processes of hardening treatment by explosion are carried out under high pressure of the shock waves. The simultaneous change of plasticity and the possibility of the metal continuity disturbance is very often not taken into consideration, especially at the level of microcracks, which is inadmissible for the operating conditions.

Fundamental studies of the defect accumulation phenomenon and of the formation of submicrocracks under static tension of samples of armco-iron, nickel and Hadfield steel have been reported by Oding and Liberov. It has been found that submicrocracks appear in the microstructure on reaching a certain critical deformation which is expressed by a specific elongation value of the order of 10 %.

The deformation degree (ρ) as a function of the actual pressure (P) has been studied under the action of plane shock wavers in devices which preclude any shift of the lateral sides of the: sample and create uniaxial deformation. Explosive treatment was applied for samples of 110Г13Л steel, nickel and steel 20. The degree of deformation was determined by the change of the volume in the compressed state (1), and the pressure value was obtained from the expression for the case of uniaxial deformation (2)

$$\varepsilon = {}^{4}\!/_{3} \ln \frac{c + (\lambda - 1)u}{c + \lambda u}, \qquad (1)$$

$$P = \rho_0 (c + \lambda u) u, \qquad (2)$$

where c and λ is the local sonic speed and the material compressibility coefficient respectively, u – mass velocity, ρ_0 – metal density.

The calculated relationship $\varepsilon = f(P)$ is shown in the Fig. 1 by dotted curves 2, 4, 6. The continuous curves 1, 3, 5 in the same Fig. 1 show the relationship between the specific elongation (δ) and the actual pressure value for the samples preliminary hardened by shock waves and which were subsequently statically tested for uniaxial tension.

An analysis of the obtained relationships shows that the paint of intersection of the curves ε and δ for each metal determines the pressure in the shock wave and the degree of deformation corresponding to that pressure. In such case the ε values which correspond to the pressure value may be considered as the ultimate parameters precluding the formation of submicrocracks. Thus, in the intersection point of curves ε and δ the uniaxial tensile deformation during elimination of the load in the shock wave is equal to the deformation value which can be withstand by the hardened sample without its failure under the subsequent static deformation. From the Fig. 1 it further follows that when the pressures in the shock wave exceed those; in the intersection points of curves ε, the deformations grow and during load elimination failure occurs. With the increase of the pressure the difference of $\varepsilon - \delta$ is increased, thus the probability of the growth in the quantity of sub-microcracks is also increased. And on the contrary, when the pressures in the shock wave are lower in the intersection point of curves ε, δ, the deformation in the shock wave is lower and the; formation of sub-microcracks is eliminated. From the Fig. 1 it is seen that the ultimate parameters for the specified materials are:

- for 110Г13Л steel $P = 20.0$ GPa, $\varepsilon = 13.6$ %;
- for nickel $P = 24.3$ GPa, $\varepsilon = 12.7$ %;
- for steel 20 $P = 11.4$ GPa, $\varepsilon = 10.1$ %.

Thus, the value of the ultimately tolerable: deformation during the treatment of low-carbon steel by shock waves coincide with the data obtained by Oding and Liberov for armco-iron. An experimental confirmation of the conditions for the formation of submicrocracks was obtained on the steel 20 samples. The initial pressure of the shock wave generated in the sample equaled 42.5 GPa. Propagating into the depth of the sample, the shock wave became weaker, and at a distance of 12 and 17 mm from the surface the pressure value equaled 20.0 and 13.0 GPa respectively. The submicrocracks were revealed by electron microscopy, by preparation of carbon replicas which were scanned strictly sectionwise (1st, 2nd, 3rd section, etc.). The replicas without shading were studied under the "Tesla" electron microscope at accelerated 60 kV voltage[1]. The studies revealed submicrocracks in the slip striations at a 1–17 mm distance, as well as at the grain boundaries. At a distance of more than 17 mm from the surface of the shock wave: penetration no submicrocracks were observed. Thus, the conclusions obtained by calculations have been confirmed experimentally. The results of the studies which revealed the submicrocracks deeply located from the perturbation source and which showed the conditions of their formation, were so unexpected that made to look at the problem of metal hardening treatment by explosion from an absolutely new viewpoint. On the one hand, the treatment of metals by powerful shock waves (to the right of the intersection point of the δ and ε curves in the Fig. 1) when the hardening deformation mechanize accompanied by phase transformations is realized to the full extent, proved to have no prospects due to the formation of latent defects. On the other hand, if the possibility of metal hardening treatment by explosion under the action of relatively moderate: pressures (to the left of the intersection point of the δ and ε curves in the Fig. 1) is considered, and then the effectiveness of such treatment is extremely low which is expressed by a weak change in the metal strength parameters. Therefore, the fact of the development and employment of the conditions for explosive metal hardening is noteworthy since. It creates high pressures which result in substantial transformations in metals without, their failure. It is possible if such loading conditions are created which substantially limit the load on the material. To this end laminated explosive charges are employed with high effectiveness, their action Is characterized by high amplitude of the pressure in combination with a substantial time of its application. For comparison, the table contains the data which characterize the change in the range of the properties of the 110Г13Л steel treated under the conditions of the "traditional" explosive hardening treatment and by using a laminated explosive charge[2].

The treatment has been carried out at practically the same pressures (to the right of the intersection point of the ε, δ curves in the Fig. 1). Attention should be paid to the plasticity indices. In the first case the plasticity characteristics have been reduced by 2.5–3 times as compared to the initial ones, while in the second case, at the same pressure, but under other treatment conditions, their values remained at the initial level. It should be also noted that the first treatment variant is indispensably accompanied by the formation of submicrocracks, while after the treatment by a laminated charge no failures have been observed.

Table. Relationship between the 110Г13Л steel mechanical properties and strengthening conditions

Strengthening scheme	Hardness HB	$\sigma_{в}$ MPa	$\sigma_{т}$ MPa	δ %	ψ %	KCV J/cm^2
Non-strengthened	180	705	430	30.0	36.0	2300
Single-layer explosive charge P = 33.0 GPa	360	1140	970	9.0	20.0	600
Laminated explosivecharge P = 31.0 GPa	412	1180	1010	22.0	28.0	1630

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[1] Electron micros-copy was carried out at the Baikov Institute of Metallurgy, Russian Academy of Sciences, under the supervision of prof. V. S. Ivanova

[2] The experiments on explosive processing of steel 110Г13Л was executed in Mechanics Research Institute of Moscow State University by Lomonosov M. V. (Russia) by the professor Kozorezov K. I.

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