IOP Conference Series: Materials Science and Engineering

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To cite this article: I Savchenko *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **969** 012079

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IOP Conf. Series: Materials Science and Engineering **969** (2020) 012079 doi:10.1088/1757-899X/969/1/012079

Modeling Dynamic Parameters of Hard Alloys during Shock Wave Regeneration

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Abstract. Construction of the shock adiabat of a porous multi-component mixture and the parameters of compression of this medium by shock waves. As a research technique for the present work, we considered the description of a solid by the equations of hydrodynamics when a shock wave propagates through a substance or mixture of substances when the shock compression pressure exceeds the yield strength of the medium components. When shock-wave compression of solids is determined, the parameters of the medium during its multiple compression using the equations of state of multicomponent systems, which are represented by continuous analytical dependencies. The fundamental possibility of using shock-wave processing as a factor stimulating the processes of destruction of powder products of any configuration to obtain high-quality powder for further formation, sintering, and production of tools for various purposes is shown, using developed dependencies. Technology for the regeneration of hard alloys is developed, an environmentally friendly processing technology is proposed super hard materials, cermet components of obsolete military equipment, and different types of ammunition.

1. Introduction

Striving for dominating positions in the market, encourages the leadership of the countries and large companies, as well as other influential stakeholders of today’s world, to develop an innovative approach to business processes engineering reengineering to increase the economic and overall business performance leading to higher revenues. The implementation of innovative approaches will allow to increase business efficiency, which calls for traditional tried and tested approaches and methods to be adapted for the development of modern society [1].

It is necessary to determine multiple compressed medium parameters for the process of shock wave compression in solids. This task can be made relatively easy and performed in the case of single-component systems, but the task gets complicated in case of the dynamic systems compression, which consists of several components. In this case, it is necessary to determine the equation of multicomponent systems state, which are to be represented with continuous analytical dependencies or, Experimental data on shock compressibility for many metals, rocks, minerals, and other substances was published [2–7].

2. The main part of the article

There are several methods of tungsten cobalt hard alloys scrap regeneration: pyro and hydrometallurgical, chemical (chlorine, zinc), thermochemical, and using explosion energy of blasting explosives. The first two methods are very complicated, multi-staged, and laborious, requiring equipment that is stable in aggressive mediums and consuming a lot of electricity. The final products of these methods are composite compounds of tungsten, which require additional processing. Besides, all of these imply harmful work conditions and contamination of the environment [8–13].

The purpose of these studies is to form the shock adiabat of a porous multi-component mixture along with the shock wave compression of the medium. The equation of the shock wave adiabatic of the material $P=P(\rho)$ is widely used for the calculation purpose, which is based on the experimental dependency between the speed of the shock wave D and the mass speed at its front $D=c_0+\lambda u$, where c_0 – hydrodynamic sound speed, λ – material constant. Basis this dependency and the mass and impulse conservation laws at the front of the shock wave, we shall have the following result [14–17].

$$P=\frac{\rho_0 c_0^2\left(1-{\rho_0}/{\rho}\right)}{\left[1-\lambda\left(1-{\rho_0}/{\rho}\right)^2\right]^2}; \tag{1}$$

$$E=E_0+\frac{1}{2}\left[\frac{c_0\left(1-{\rho_0}/{\rho}\right)}{1-\lambda\left(1-{\rho_0}/{\rho}\right)}\right]^2 \tag{2}$$

where P and E – pressure and energy at Hugonio curve; ρ – front shock wave density; ρ_0 – initial density of the material. Boundary compression value is determined, provided: $1-\lambda\left(1-{\rho_0}/{\rho}\right)=0$. Resulting

$$\frac{\rho}{\rho_0}=\frac{\lambda}{1-\lambda}=\frac{1}{1-1/\lambda}. \tag{3}$$

When plotting shock adiabat of multicomponent mediums at 10 GPa and higher pressure, the hydrodynamic model is used since the process of the shock wave propagation only slightly depends on the initial conditions. Usually, multicomponent media are considered which, likewise mixtures, have no volume defect:

$$V=\frac{1}{\rho}=\sum_{i=1}^{n}\alpha_i V_i \;;\sum_i \alpha_i=1 \tag{4}$$

where V_i – the specific volume of the ith component of the medium; α_i – weight fraction; V – specific volume of the whole medium.

In addition to this, it is considered that a multicomponent medium is a homogeneous medium. This assumption is a consequence of the fact that the shock adiabat of the medium at high pressures is weakly dependent on the structure of the medium, starting with some grain size. The single-phase model of the medium, in turn, assumes single temperature, single-speed model of the medium, whose thermodynamic properties can be described based on the Mi-Gruneisen type equations with the thermal part of pressure and energy, determined by the Debye theory.

The study [18] demonstrates the possibility of constructing a substance shock adiabat using only the value of the volumetric (hydrodynamic) sound velocity in this substance and the following dependence $P(\mu)$, where $\mu = u/c_0$. Dimensionless coordinate $P = Du / c_0^2$; $\mu = u/c_0$.

Experimental data on the dynamic compressibility of metals and minerals data represented by generalized shock adiabatic [19]. For a mixture of two substances (solid or liquid) in the absence of experimental data, sound velocity can be calculated using the formula recommended in the study [20].

$$\frac{1}{\rho_0 c_0} = \frac{\alpha}{\rho_{01} c_{01}} + \frac{1-\alpha}{\rho_{02} c_{02}}, \tag{5}$$

where α – the weigh share of the first component; ρ_{01}, ρ_{02}, c_{01}, c_{02} – density and sound velocity of the first and second components respectively.

The construction of the shock adiabat of the non-porous mixture of two solids is based on the following assumptions: provided the equality of mass velocities of the components along the front of the shock wave, the distribution of energies by the components is proportional to their mass content.

When constructing the shock adiabat [21-22] the following assumption was made – when the shock wave propagates on the sample of the non-porous mixture, the pressure in both components on the shock wave front is leveled and no heat exchange occurs. In this case, the mass velocity of the two materials mixture particles is determined by the formula:

$$u_{\text{см}}^2 = \alpha \cdot u_1^2 + (1-\alpha) u_2^2 . \tag{6}$$

The specific volume of the mixture in the initial state and the final state is calculated using the following ratios:

$$V_{\text{см}} = \alpha V_{01} + (1-\alpha) V_{02} \tag{7}$$

where V_{01}, V_{02} – specific volumes of the first and the second components in the initial stage and at the shock wave front respectively.

The basic assumption is used in the construction of the shock adiabat of a porous medium: a solid is a non-porous mixture of two solids for which the relation (5 – 7) is true. This assumption was based on the fact that the constants c_0 and λ, which characterize the dynamic compressibility of solids, do not differ much, which allowed building the equation of the porous medium, where hydrodynamic sound velocity c_0 and the λ_{0n} parameter in the equation $D = c_0 + \lambda_{0n} u$ are generalized and dependent on the corresponding c_{0i} and λ_i components.

The specific volume of the medium in the initial stage, before the shock wave front, is also calculated: $V_{0\text{см}} = \sum_{i=1}^{n} \alpha_i V_{0i}$. Substituting ρ_i we shall establish the final dependency $\rho_{cm} = \rho_{cm}(P)$:

$$\rho_{\text{см}} = \left[\sum \left\{ \frac{1}{\rho_{0i}} \alpha_i \left[1 - \left(\sqrt{\frac{\rho_{0i} c_{0i}^2}{4\lambda_i^2 P} + \frac{1}{\lambda_i}} - \frac{c_{0i}}{2\lambda_i} \sqrt{\frac{\rho_{0i}}{P}} \right)^2 \right] \right\} \right]^{-1} \tag{8}$$

Therefore, knowing the shock compressibility adiabats of each i-th component (c_{0i}, λ_i), the dependency $P = P(\rho_{\text{см}})$ can be constructed (8).

The $\rho_{0\text{см}}$ shall be calculated using expression (5):

$$\rho_{0\text{см}} = \frac{1}{V_{0\text{см}}} = \frac{1}{\sum_{i=1}^{n} \alpha_i V_{0i}} = \frac{1}{\sum_{i=1}^{n} \frac{\alpha_i}{\rho_{0i}}} \tag{9}$$

Now it will be easy to calculate λ_{cm}:

$$\lambda_{см} = \left(\frac{\tilde{\rho}_{см}}{\tilde{\rho}_{см} - \rho_{см}}\right) = \left[1 - \frac{\sum_{i=1}^{n} \alpha_i V_{0i}\left(1 - {}^{1}\!/\!_{\lambda_i}\right)}{\sum_{i=1}^{n} \alpha_i V_{0i}}\right]^{-1} \tag{10}$$

Feeding λ_{cm} and c_{0cm}, the shock wave adiabatic of the mixture in (P, $\rho_{см}$) coordinates, will be presented as follows:

$$P = \frac{\sum_{i=1}^{n} \frac{\alpha_i}{\rho_{0i}}\left(1 - \left[\rho_{см}\sum_{i=1}^{n}\frac{\alpha_i}{\rho_{0i}}\right]^{-1}\right)}{\left(1 - \frac{\sum_{i=1}^{n}\frac{\alpha_i}{\rho_{0i}}}{\sum_{i=1}^{n}\frac{\alpha_i}{\rho_{0i}\lambda_i}}\left(1 - \frac{1}{\rho_{см}\sum_{i=1}^{n}\frac{\alpha_i}{\rho_{0i}}}\right)\right)^2 \sum_{i=1}^{n}\frac{\alpha_i}{\rho_{0i}^2 c_{0i}^2}}. \tag{11}$$

Figure 1 illustrates the calculated shock adiabats in (P - u) coordinates for tungsten, containing hard alloys: VK8 – 1, carbon, which contains – 5,642 % weight, cobalt – 8 % weight, and tungsten – rest (curve 1); VK15 – 2, carbon, which contains, – 5,213 % weigh, cobalt – 15 % weight and tungsten – rest (curve 2), VN8 – 3, carbon, which contains, – 5,642 % weight, nickel – 8 % weight and tungsten - rest (curve 3); VN15 – 4, carbon, which contains, – 5,213 % weight, cobalt – 15 % weight and tungsten – rest (curve 4). Using the established dependencies, the technology of hard alloys regeneration was developed [1].

Marketing strategy implies offering the international quality standard product at 5–10% less than the market price [1].

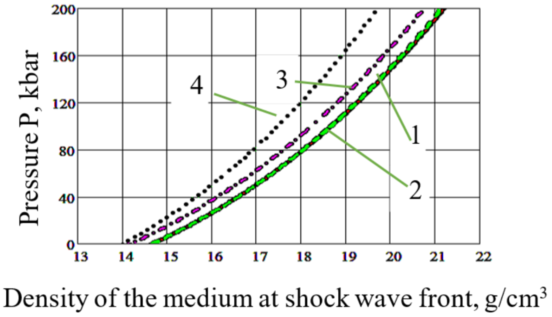

Figure 1. Impact of adiabat.

New technology is resistant to negative factors. The center can operate at no loss, selling over 11 tons of products a year. In the case of a price drop by 10–20% or material cost increase by 20–50%, product profitability will reach 60–70%, which is still rather high.

Economical indices of the project are as follows:

- net present value (NPV) for the settlement period of project realization (5 years) is over 1265 thousand USD, which corresponds to the effectiveness condition, where NPV should be >0;
- investments profitability index (JR) – 6,0 (JR>1);
- recoupment of capital investments is 8 months from the issuance of the loan.

Industrial development of the above-described technology, within a short timeframe, will allow solving several important issues:– hard alloys scrap utilization, its further reduction and consequent significant cut down of raw material usage;– making use of new technology which omits low productive ways of deficit raw material utilization and manufacturing products of international quality standard.

3. Conclusions

The obtained equation of the shock adiabat of hard alloy allowed to optimize, in terms of defect formation, the load parameters of the processed materials. The propagation of the shock wave through a substance or mixture of substances when the compression pressure exceeds the flux limits of the medium components is described by the hydrodynamic equations regardless of the aggregate state of the substance, that is, the solid, as well as the fluid, is described by the variables pf pressure P and volume V. Fundamental potential of shock–wave treatment as a stimulating factor for powder products destruction of any configuration, to obtain high-quality powder for further formation, caking and production of tools of multiple uses was demonstrated.

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