Simulation of multi-contact wave strain hardening

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Abstract. The article raises the problem of reducing pressure in the deformation zone during hardening of plastic materials by shock pulses. It is proposed to use the method of wave strain hardening and its multi-contact loading scheme as its solution. To accelerate the study of the influence of WSH technological parameters on the process of plastic material hardening, its finite element modeling is used. From the obtained patterns, the most significant technological parameters of the multi-contact WSH process were established and the ranges of their values providing effective hardening of plastic materials are given.

1 Introduction

Improving the mechanical characteristics of aluminum alloys of the AMG brand is an urgent task of modern engineering. The widespread use of AMG alloys in most industries is due to the fact that the material, with a small weight, has sufficiently high mechanical characteristics. Due to the AMG alloy properties, a further increase in its mechanical characteristics is possible due to hardening by the methods of surface plastic deformation (SPD). One of the most effective SPD methods, allowing to act on the loaded surface with prolonged shock pulses, is to strike through an intermediate link in the process of wave strain hardening (WSH). Preliminary static loading does not allow the waveguide to come out of contact with the treated surface after impact, thereby ensuring the recovery of the reflected deformation waves. Under WSH, the use of loading by controlled shock pulses gives greater opportunities for the formation of a hardened surface layer with a large depth (up to 6 ... 8 mm), a high degree (up to 6500 MPa) and the required uniformity of hardening (with the possibility of obtaining a heterogeneous structure that increases durability). The uniformity of overlap of plastic prints is estimated through the overlap coefficient K . The range of K variation is from 0 to 1: at $K = 0$, the prints do not overlap, the edges of the prints border each other; at $K = 1$, the prints completely overlap [1].

One-contact WSH circuits have proven themselves well for creating hardened areas at great depths in steel products due to the intense impact on the deformation zone. However, the use of single-contact WSH circuits for hardening a plastic material, such as an AMG alloy, is hindered by the probability of its destruction due to excess pressure in the deformation zone.

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The possibility of hardening of plastic materials is achieved through the use of multi-contact WSH circuits. This makes it possible not only to reduce the pressure in the deformation zone up to 10 times, but also to increase the processing productivity [2,3]. Under the condition of multi-contact WSH, it becomes necessary to additionally take into account such technological parameters as: S_{rat} - the ratio of the sum of the cross-sectional areas of the instruments and the cross-sectional area of the waveguide; N_T - the number of tools in the loading system, pcs; p is the total pressure in the deformation zone, MPa.

Studies of the features of multi-contact wave strain hardening are, as a rule, rather laborious (a large amount of data for research) and long-term (preparation and hardening of samples, laboratory studies of the obtained physical and mechanical properties of the hardened material). It is possible to obtain the necessary information related to technological patterns and the possibilities of wave strain hardening in the processing of various materials by modeling the process. The use of the existing analytical model of the wave strain hardening process and the computer program created on its basis is constrained by a number of limitations [1, 4]. So, the physical and mechanical properties of the processed material are taken into account semi-experimentally, without taking into account hardening curves; hardening is carried out with only one tool; hardness (stress, strain) formed in the loading medium as a result of the calculation can be determined only at one point under the tool imprint, but not by the material equidistant surface.

Therefore, the available theoretical data on the strengthening of the material by the deformation wave are applicable only to single-contact shock systems containing one bar-shaped tool. Their use for the analysis of multi-contact loading schemes is difficult. The aim of this paper is to establish as a result of modeling the influence of technological parameters of multi-contact WSH on the process of plastic material hardening.

2 Materials and methods

It is possible to solve the problems associated with changes in the physical and mechanical properties with respect to the material surface equidistant and deeper under load through the use of finite element modeling methods [5-9]. Among the programs based on the finite element method, one of the world leaders in reliability and functionality in the field of simulation: processes of plastic deformation and testing of mechanical properties, is LS-DYNA.

The development of the finite element model of multi-contact wave strain hardening was carried out in several stages.

At the first stage, finite-element models of hardened materials (loading media) are created based on the specification of material behavior parameters according to the results of accumulated experimental data. For this, the physical and mechanical properties of the loaded medium are set on the basis of templates of material models presented in ANSYS/LS-DYNA. Since elastoplastic deformation of the material surface occurs in the process of wave strain hardening, a model template selected by the Piecewise Linear function is chosen. In it, as the parameters determining the material, density, Young's modulus, Poisson's ratio, effective deformations, as well as a piecewise-linear graph of the dependence of stress on deformation at 10 points are introduced. To ensure the calculation accuracy, the material parameters obtained experimentally as a result of its uniaxial tensile tests are introduced into the model template. The assessment of the material model adequacy is carried out as a result of comparing the obtained data with the accumulated experimental ones, for example, the sizes of single prints of tool strokes and the change in the degree of hardening under single prints are compared.

At the second stage, a finite element model (FEM) of the shock pulse is formed in a single-contact shock system with an intermediate link. The creation of a FEM for the

formation of a shock pulse in a single-contact shock system is performed in the ANSYS/LS-DYNA module (specially designed for modeling fast processes). FEM of a shock system includes a firing pin-waveguide-tool and a loaded medium. In the created shock system, the tool – the rod roller (D_t is a diameter and l is the tool length) is statically pressed to the loaded medium by the waveguide with the force P_{st} ($P_{st} = 0.1P_{sh}$) [1], and the striker delivers a single blow to the waveguide at a speed of V , m/s. The energy A of the shock pulse is estimated in the model, in the plane of the loaded medium under the tool according to the procedure [1]. The reliability of the simulation is established as a result of comparison with previously obtained experimental data [1,2].

At the third stage, a finite element model of the formation of a shock pulse in a multi-contact shock system is created. The FEM includes several tools statically pressed to the loaded medium through a single waveguide, in which a single blow is applied at a speed of V , m/s. The simulation reliability is established as a result of comparison with previously obtained experimental data.

At the fourth stage, a finite element model of the process of single-contact and multi-contact wave strain hardening of continuous material is formed. The physical and mechanical properties of the processed material and the parameters of the shock system are established. The data obtained in steps 1–3 make it possible to create an energy-efficient shock system, which forms the basis of the finite element model of the process of wave strain hardening of continuous material. Its creation in the ANSYS/LS-DYNA program is carried out from the preparation of the process in the Preprocessor module, in which the following are set: model geometry, finite element mesh, element type, material models are determined. To prepare the FEM for calculation, the Solution module also sets: contact of objects, load applications, boundary conditions, calculation parameters. The output of graphic and textual information of the obtained results (energy, stress, strain, etc.) for a specific point in time is performed in the General Postproc module.

3 Investigation of the influence of technological parameters of multi-contact WSH on the process of plastic material hardening

Testing of the created finite element model of multi-contact wave-like strain hardening was carried out on flat samples of plastic material of the AMG brand. All the data obtained during the simulation correspond to the results of the experiment with a confidence level of 0.95.

As a result of the simulation data analysis, it was found that with multi-contact WSH, the following technological parameters have a significant impact on the depth and degree of the surface layer hardening: A - impact energy, D_T - tool diameter, K - coefficient of overlap of plastic prints, as well as the number of passes during processing.

The areas of change in the values of the main technological parameters of WSH during the processing of materials lie in the following range: $A_{min} \dots A_{max} = 5 \dots 80$ J; $D_{Tmin} \dots D_{Tmax} = 8 \dots \infty$; $K_{min} \dots K_{max} = 0.2 \dots 0.8$.

In the case of a single impact, the most effective are tools in the form of a ball and a cylindrical rod with a spherical end face at: $D_T = 19 \dots 27$ mm and $A = 30 \dots 50$ J. The greatest depth of hardening is provided at $K = 0.2 \dots 0.6$, if balls 27 mm in diameter are used as tools, or cylindrical rods with a sphere diameter at the end of 27 mm.

The maximum depth and degree of the surface layer hardening (up to 10 mm and 110%, respectively) with multi-contact WSH are provided when the ratio of the total area of the tools and the area of the waveguide S_{rat} in the range from 0.2 to 0.8 and the number of tools N_T in the loading system is not more than 3.

The study of multi-pass processing has established the maximum number of passes for each mode: for $K = 0.2$ - 3 passes, for $K = 0.4$ and 0.6 - 2 passes each. Further processing

leads to hardening and negatively affects the surface layer quality.

4 Conclusion

1. It has been established that hardening of a plastic material without its destruction by shock pulses with high energy is possible due to the use of multi-contact loading schemes. The use of multi-contact circuits allows to reduce the pressure in the deformation zone up to 10 times.

2. It was found that during multi-contact processing of the area of changes in the values of the main WSH technological parameters lie in the following range: $A_{min} \dots A_{max} = 5 \dots 80$ J; $D_{Tmin} \dots D_{Tmax} = 8 \dots \infty$; $K_{min} \dots K_{max} = 0.2 \dots 0.8$.

3. It was revealed that with multi-contact WSH of plastic material with balls with a diameter of 27 mm and cylindrical rods with a sphere diameter at the end of 27 mm, at $K = 0.2 \dots 0.6$, the greatest depth of hardening is provided.

4. It has been established that with multi-contact WSH the maximum depth and degree of the surface layer hardening are provided (up to 10 mm and 110%, respectively) with a ratio of the total area of the instruments to the area of the waveguide S_{rat} in the range from 0.2 to 0.8 and the number of instruments N_T in the loading system of no more than 3.

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References

1. A.V. Kirichek, D.L. Soloviev, A.G. Lazutkin Technology and equipment for static-pulse treatment by surface plastic deformation, *Mech. Eng.*, 288 (2004)
2. A.V. Kirichek, S.V. Barinov, A.V. Yashin, *Key Eng. Mater.*, **736**, 12 (2017)
3. A.V. Kirichek, S.V. Barinov, A.V. Aborkin, A.V. Yashin, A.A. Zaicev, *IOP Conf. Series: Mater. Science and Eng.*, **327**, 042011 (2018)
4. A.V. Kirichek, A.N. Afonin *Proceed. 2010 Joint China-Russia Sympos. on Adv. Mat. and Proc. Tech.*, Harbin, 137 (2010)
5. G. Strang, G. J. Fix, *An Analysis of the Finite Element Method* (Prentice-Hall, 1973)
6. E.G. Thomsen, T.Y. Charles, S. Kobayashi, *Mechanics of plastic deformation in metal processing*, 486 (1965)
7. S. Kobayashi, S. Oh, T. Altan, *Metal Forming And The Finite Element Method* (Oxford University Press, New York, 1989)
8. V.E. Eremjants, V.V. Niu, *Mod. prob. of theory of mash*, **4**, 123 (2016)
9. V.E. Eremjants, V.V. Niu, *Journ. of Adv. Res. in Tech. Science*, **2**, 20 (2016)