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IMPROVING THE TECHNOLOGY FOR MANUFACTURING ELECTRIC VEHICLE TRACTION BATTERY HOUSINGS TO PROTECT AGAINST IMPACT DAMAGE

On modern electric vehicles, the traction battery is installed from below on the bottom of the body, which reduces the height of the vehicle's center of gravity and improves the vehicle's lateral stability during curved movement. The disadvantage of this arrangement is the increased risk of damage and destruction of the protective housing and, accordingly, the battery's electrical elements, which are dozens of ordinary household lithium-ion batteries of the AAA type. But the housings of these electrical elements are manufactured using a special technology that helps increase the strength of the housing and from a material with high heat dissipation. It is shown that the traction battery is the most expensive component of an electric vehicle. Therefore, the development of production methods aimed at increasing its service life is an urgent task.

The mechanical characteristics of anisotropic material were taken into account during the manufacture of reinforced containers for electrical element housings. Data were determined that reliably reflect the influence of the stretching coefficient, planar anisotropy and the initial diameter of the work piece on the critical thickness of its plate. An expression was obtained that takes into account all the characteristics of the technological process that affect the thickness of the initial work piece. This allows you to control these characteristics in order to optimize the thickness of the work piece. The dependence obtained as a result of the study allows you to accurately and qualitatively calculate the optimal thickness of the initial work piece at the stage of developing the technological process for manufacturing battery cell housings for electric vehicles.

Key words: electric car, lithium-ion battery, battery protection, anisotropic materials.

INTRODUCTION

Electric cars are becoming widespread due to environmental friendliness, efficiency, cheapening their production, increasing the power reserve on a single charge and developing the infrastructure for their maintenance. In general, compared to an internal combustion engine, an electric motor loses less energy by friction, does not require a complex lubrication system and almost does not wear out. Therefore, many modern electric vehicles have a power plant with a capacity of 368 + kW and accelerate faster than cars with internal combustion engines. For example, Porsche Taycan Turbo S electric motors develop a power of 560 kW and accelerate the specified vehicle to 100 km/h in 2.8 s [1].

The most expensive component of an electric car is a power battery. It consists of a certain number of standard batteries that form a battery of the desired voltage, operating current and power. The combination of such a set is determined by the structure of the electric vehicle power system. Its shape and volume is determined by the layout of the electric vehicle.

In order to reduce the height of the center of mass of the electric car, manufacturers place traction batteries on the bottom of the body. To do this, make the battery as a separate module, which has a minimum height. Or install several modules of traction batteries of different sizes for different places of the electric car.

However, this solution increases the likelihood of physical damage to the lower wall of the traction battery housing, which can lead to the impossibility of movement and the release of hazardous substances. Therefore, traction batteries for electric vehicles are manufactured using a special technology that increases the strength of the battery case and uses materials with high heat dissipation. In addition, the development of production methods aimed at increasing the service life of traction batteries is an urgent task.

LITERATURE REVIEW AND PROBLEM STATEMENT

THE IMPLEMENTATION OF THE ABOVE-DESCRIBED DESIGNS OF TRACTION BATTERIES FOR ELECTRIC VEHICLES LED TO THE EMERGENCE OF A COMPLETELY UNDERSTANDABLE SOLUTION – THE DEVELOPMENT OF A REINFORCED DESIGN OF THE BOTTOM OF THE BATTERY CASE [2].

Typical materials for standard AAA battery housings are polyethylene or polypropylene based materials. The problem with using polymers for the housing is that these materials have a low thermal conductivity and therefore create unfavorable thermal conditions for traction batteries when they are heated during a significant load on the power system.

But the metal walls of the traction battery housing, due to greater elastic and plastic deformation, can better withstand impacts. The disadvantage of metal walls of the housing is their significantly greater weight. The greater weight of the metal wall is also a consequence of the use of their manufacturing technology.

One of the directions for reducing the weight of the metal wall of the traction battery housing is the optimal choice of the thickness of the work piece. It is necessary to take into account the mechanical characteristics of the metal when manufacturing reinforced housings for electrical elements.

During cold deformation of metals, it is necessary to take into account the effect of hardening and initial anisotropy of the metal on the final and intermediate stages of forming [3].

During plane anisotropy, an additional load is applied to some parts of the internal contour of the work piece and simultaneous unloading of others [4].

However, the calculation of the stability of compressed sections of a sheet metal work piece during cold deformation is a typical problem of the theory of plasticity [5]. And to obtain a satisfactory solution for determining the ultimate thickness of the work piece for the drawing process, it is necessary to take into account the phenomenon of metal hardening and anisotropy of the mechanical properties of the metal [6].

PURPOSE AND OBJECTIVE OF THE STUDY

The purpose of the work is to theoretically justify the initial thickness of the work piece from which, due to the deformation hardening and anisotropy of the mechanical properties of the material, more durable housings of battery cells can be made. Further theoretical research aimed at taking into account all the features of the production technology of metal battery cases in order to justify the choice of thickness of blanks to reduce their weight.

RESEARCH RESULTS

During the flat anisotropy, in comparison with the drawing, the isotropic material there is an additional load of some parts of the inner contour of the blank flange and simultaneous unloading of others. This process significantly worsens the conditions of the hood. As a result, corrugations and festoons are formed on the end of the work piece. Consequently, it is necessary to take into account the phenomenon of strengthening and anisotropy of the work piece due to the accurate calculation of the stress and deformation fields of the work piece. It is also necessary to determine the intervals of unpressurized stamping. To do this, it is effective to use theoretical models that are more adequate in describing the physical process of cold deformation.

The main condition for a successful sheet metal plastic deformation process is to maintain the stability of the sheet metal plastic formation process. In the event of a loss of form stability, significant local deformations occur, which usually leads to a rupture of the work piece or to a marriage. Ensuring the stability of the plastic forming process reduces the percentage of defects, improves the quality of the product and contributes to the reliable operation of automatic machines.

Based on the Euler scheme, the occurrence of waviness of the sheet surface is formed in areas with excessive compressive or compressive-tensile stresses.

Most of the published work on this type of buckling concerns the formation of waviness on a flat flange during deformation of parts such as bodies of revolution. In the analyzed works, the solution of the problem of flange stability was considered by analogy with the solution of the problem of elastic-plastic bending of a compressed rod by the Engesser-Karman method. It was assumed that the formulas for the elastic bending of plates and shells are valid for the case of bending beyond the elastic limit of the metal. To do this, the modulus of elasticity should be replaced by the reduced modulus of elasticity.

The exact solution of the problem of analyzing the stress state of the flange of the sheet anisotropic work piece during deep plastic deformation has certain mathematical difficulties. To obtain a solution to such a problem, a number of assumptions were made: we neglect the change in the thickness of the blank flange, that is, we believe that its flange is in conditions of flat deformation; plastic orthotropy of sheet metal arising in the process of plastic deformation of anisotropic material is rather small and does not have a significant effect on its initial anisotropy; there is no Bauschinger effect; metal behavior obeys the laws of elastic-plastic hardened medium in the corrugation zone; forces increase slowly and deformation rates are small; plastic deformation process is considered to be a uniform deformation process consisting of a set of consecutive balanced plastic states, each of which corresponds to a certain stage of loading. To obtain a satisfactory solution for determining the limit thickness of the work piece for the drawing process without pressing, it is necessary to take into account the phenomenon of metal hardening and anisotropy of the mechanical properties of the metal. Make assumptions allow you to find a solution on the basis of which you can determine the parameters of the tool and work piece; determine the parameters of technological operations that do not lead to defects.

In work [7], dependencies for calculating the critical thickness of an anisotropic work piece without corrugation are shown

$$s_k = \frac{3}{\pi} b \sqrt{2\mu|\sigma_u| \frac{L_k}{E_p}}, \tag{1}$$

where b – flange width; μ – coefficient that depends on anisotropy; σ_u – main normal tangential stresses acting in the direction of the anisotropy axis;

$$L_k = \frac{N}{M};$$

$$M = B_1 \frac{b^2}{a^2} + B_2 \frac{a^2}{b^2} + B_3;$$

$$N = F_1 + F_2 \frac{a^2}{b^2};$$

$$B_1 = \frac{3}{2}\left(\frac{3}{2} - \frac{4}{\pi}\right)\left(\frac{c_{22}}{g} - \frac{4\psi}{3K_\sigma}\right);$$

$$B_2 = \frac{3}{64}\left(\frac{c_{11}}{g} - \frac{\psi}{K_\sigma} m_\sigma^2\right);$$

$$B_3 = \frac{3}{4c_{33}} + \frac{3}{2}\left(\frac{1}{\pi} - \frac{1}{4}\right)\left(\frac{c_{12}}{g} + \frac{4\psi}{3K_\sigma} m_\sigma\right);$$

$$F_1 = \left(\frac{3}{2} - \frac{4}{\pi}\right)\beta;$$

$$F_2 = \frac{1}{8} m_\sigma;$$

$$\psi = \frac{3}{4}(1 - n);$$

$$g = c_{11}c_{22} - c_{12};$$

$$K_\sigma = c_{11} + 2c_{12}m_\sigma + c_{22}m_\sigma^2;$$

$m_\sigma = \sigma_v/\sigma_u$ – the ratio of the main normal stresses in the anisotropy axes; E_p – modulus of plasticity of anisotropic material; n – constant value (strengthening index) that characterizes the ability of the metal to strengthen; a – half a wave length; β – the coefficient is selected within c_{11}, c_{12}, c_{22} – anisotropy constants.

In work, the data obtained from the results of a study similar to the above are given for the relative critical thickness of the plate, which provides stretching without corrugation, taking into account anisotropy: for steel 08kp – $s_к$ = 0,0247±0,0003, for brass – $s_к$ = 0,0299±0,0004.

Previously [8], dependencies have been obtained to calculate the thickness of the preform, which provides stretching without pressing the flange. The results of these calculations have some discrepancies with the empirical expressions of Schofman L. I. The thickness of the plate determined from them is somewhat larger, which leads to an increase in the weight of the final product. Therefore, it becomes necessary to finalize the theoretical result by taking into account the strengthening and anisotropy of the starting metal of the work piece.

We will clarify the resulting dependencies in accordance with assumptions that are consistent with the theory of plasticity of the anisotropic body of R. Hill: plastic orthotropy of sheet metal; sheet metal anisotropy acquired during plastic deformation is insignificant and has no significant effect on its initial anisotropy; the work piece material is compressed; metal strengthening isotropic; no Bauschinger effect.

The expression for the cross section of the anisotropic metal module of the work piece will be

$$E_{c\alpha} = \mu c_{11} E_c, \tag{2}$$

For a material with circular symmetry at $R_x = R_y = R_0$; $R_{xy} = \frac{R_0}{1 + 2R_0}$; $c_{11} = c_{22}$; $\Delta = 0$; $c_{13} = c_{23} = 0$ from (2) we will have

$$E_{c\alpha} = \frac{3}{2} \cdot \frac{1+R_0}{2+R_0} E_c, \quad (3)$$

Taking into account the anisotropy, we will find the

$$\sigma_r = \frac{1}{\sqrt{\mu\psi}} \sigma_{ec} \ln \frac{r_H}{r}, \quad (4)$$

where

$$\psi = \frac{(c_{11}+c_{12})(c_{22}+c_{12})}{c_{11}+2c_{12}+c_{22}} - c_{12},$$

$$\mu = \frac{3}{2\left(1+\frac{1}{R_x}+\frac{1}{R_y}\right)}.$$

Then the ratio to the critical thickness of the blank plate will be

$$h^2 = 0{,}041 \frac{2}{3} \frac{r_H^2}{E_c} \frac{2+R_0}{1+R_0} \frac{1}{\sqrt{\mu\psi}} \sigma_{ec} \ln \frac{r_H}{r}. \quad (5)$$

Imagine the plasticity index E_c and the average intensity of stresses, taking into account the strengthening of the material in the form of

$$E_c = C\varepsilon_i^{n-1}, \quad (6)$$

$$\sigma_{ec} = C\varepsilon_i^{n}, \quad (7)$$

where C, n – constants of the material, determined by experiments on the stretching of samples.

Substituting these formulas into expression (5) and performing the necessary transformations taking into account $\varepsilon_i = 0{,}5\varepsilon_\Theta$ we will get

$$h^2 = 0{,}041 \frac{r_H^2}{3} \frac{2+R_0}{1+R_0} \left(1-\frac{r}{r_H}\right) \frac{1}{\sqrt{\mu\psi}} \ln \frac{r_H}{r}. \quad (8)$$

We express the anisotropy coefficients μ, ψ through their parameters, substitute one of the roots of the Bessel function and as a result we get

$$h^2 = 0{,}0045 r_H^2 \frac{2+R_0}{1+R_0} \left(1-\frac{r}{r_H}\right) \sqrt{\frac{2(1+R_0)}{1+2R_0}} \ln \frac{r_H}{r}. \quad (9)$$

We will calculate for the following deformation parameters of the work piece: d = 25 mm, D = 40 mm, $R_0 = 1$.

Than

$$h^2 \geq 0{,}0045 \cdot 20^2 \cdot \frac{3}{2} \left(1-\frac{12{,}5}{20}\right) \sqrt{\frac{4}{3}} \ln \frac{20}{12{,}5} \geq 0{,}545$$

and

$$h \geq 0{,}738\,\text{mm}.$$

When comparing the results obtained from formulae [7, 8] as well as (9) with the buckling condition, it can be seen that taking into account the anisotropy of the material makes it possible to more accurately determine the critical thickness of the starting metal of the work piece. The discrepancy is not more than 8,5% (Fig. 1). In Fig. 1, the following designations are adopted: h – the thickness of the work piece, calculated according to the dependence (9); s – billet thickness calculated by L. I. Schofman's formula; r_H – initial radius of work piece.

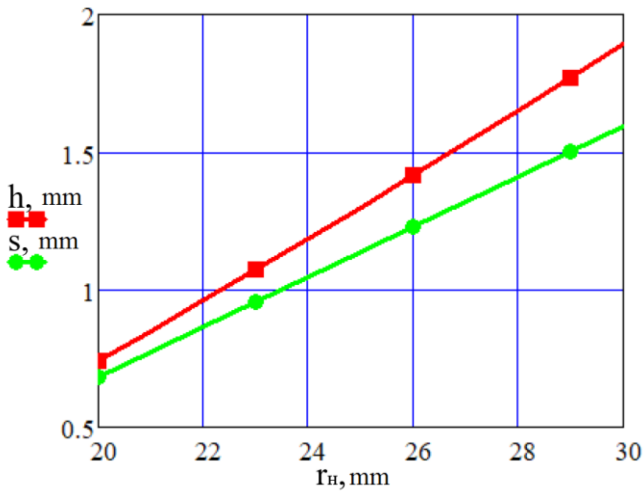

Figure 1 – Change in thickness of the work piece from its initial radius

Figure 1 shows that the results of the calculations are almost the same, but with an increase in the initial diameter of the work piece and, accordingly, the degree of deformation, the thickness increase increases for formula (9) than for the empirical equation of L. I. Shofman. This suggests that the analytical expression (9) quite adequately describes the dependence of the thickness of the work piece on its dimensions.

Analyzing the expression (9), it can be concluded that by increasing the anisotropy index from 0,5 to 2, the critical thickness of the required work piece decreases. The flange of the work piece of material with a large R0 index will be more stable under deformation. This coincides with the data of Golovlev V. D. and Zharkov V. A., who say that with an increase in anisotropy indicators, the resistance to deformation of the blank flange decreases and the limit degree of stretching increases [10]. However, flat anisotropy generally adversely affects the deformation process of the material and worsens the conditions of formation [11]. In this case, the thickness of the work piece should be increased by 1,6-2 times compared to the deformation of the isotropic metal (Fig. 2). In Fig. 2, the following designations are adopted: h is the thickness of the work piece, calculated according to dependence (9), taking into account anisotropy and the phenomenon of metal strengthening during deformation; s – billet thickness calculated by formula [10], excluding the above parameters; r_H is the initial radius of the work piece.

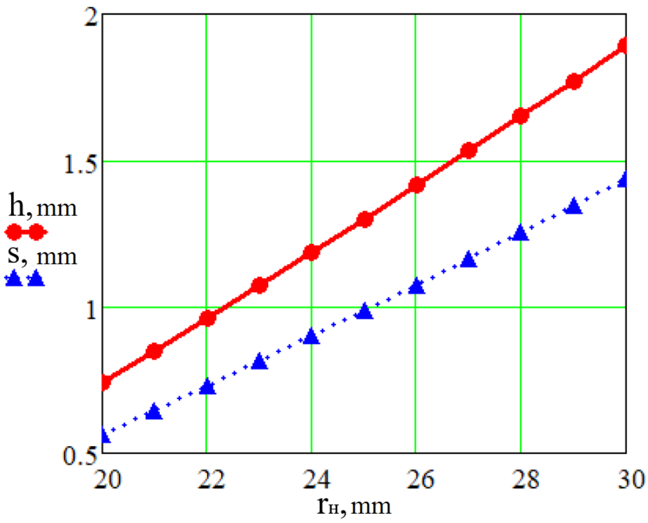

Figure 2 – Change in the thickness of the work piece depending on the increase in its initial radius

It is also interesting to compare the results of calculations with the formula of V. Golovlev (1) and experimental data [12]. We will perform the calculation for the following conditions: d = 45 mm, D = 90 mm. For steel 08kp R_0 = 1,706. We find the relative critical thickness of the plate $\bar{h} = s / D$

$$h^2 \geq 0{,}0045 \cdot 45^2 \cdot \frac{2+1{,}706}{1+1{,}706}\left(1-\frac{22{,}5}{45}\right)\sqrt{\frac{2(1+1{,}706)}{1+2\cdot 1{,}706}}\ln\frac{45}{22{,}5} \geq 4{,}785,$$

$$h \geq 2{,}19\ \text{mm}$$

and

$$\bar{h} = \frac{2{,}19}{90} = 0{,}0243.$$

According to the expression of Golovlev V. D. $\bar{h} = 0{,}0237$, according to experimental indicators Yakovleva S. S. $\bar{h} = 0{,}0247$, according to L. I. Shoffman's empirical formula $D - d \leq (18\ldots22)s$ $\bar{h} = 0{,}0227$. The greatest discrepancy between the results was found with the data of Shofman L. I. and is approximately equal to 6%.

CONCLUSION

From the above study, we can conclude that the results of calculations for expression (9) correlate well with the data obtained earlier. The determined data reliably reflect the influence of the stretching coefficient, flat anisotropy and the initial diameter of the work piece on the critical thickness of its plate. At the same time, almost all the characteristics of the technological process that affect the thickness of the initial work piece are explicitly contained in the resulting expression. This allows you to control these characteristics in order to optimize the thickness of the work piece. The dependence obtained as a result of the study allows accurate and qualitative calculation of the optimal thickness of the initial work piece at the stage of development of the technological process of manufacturing the bodies of battery cells of electric vehicles.

For example, the specific gravity of steel is 7,85 g/cm^3 and that of dense polyethylene is 0,95 g/cm^3. Then, according to simple calculations, the weight of the steel case of the battery cell with dimensions of 10x50x0,8 cm will be determined at 8,9 g, and the polyethylene case with dimensions of 10x50x2,5 cm will be only 2,79 g. That is, the polymer case of the battery cell will be lighter than the steel one almost 3 times.

Nevertheless, to protect the passengers of electric vehicles, automakers produce metal cases of battery cells. But if you increase the thickness of the steel body by 0,2 mm, the weight of the element will increase to 10,95 g, which is 2 g more than the previous calculation. Therefore, the relevance of the above study to determine a more accurate value of the thickness of the blanks of the battery cell bodies, taking into account the mechanical characteristics of their material, is not in doubt.

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Павленко О.В., Єлістратов В.О, Черниш А.А., Харьков О.А. **Удосконалення технології виготовлення корпусів тягових акумуляторних батарей електромобілів для захисту від ударних пошкоджень**

На сучасних електромобілях тяговий акумулятор встановлюється знизу на днищі кузова, що зменшує висоту центру ваги транспортного засобу та покращує поперечну стійкість автомобіля під час криволінійного руху. Недоліком такого розташування є підвищений ризик пошкодження й руйнування захисного корпусу та, відповідно, електричних елементів акумулятора, якими є десятки звичайних побутових літій-іонних акумуляторів типу ААА. Але корпуси цих електричних елементів виготовляються за спеціальною технологією, що сприяє підвищенню міцності корпусу, та з матеріалу з високою тепловіддачею. Показано, що тяговий акумулятор є найдорожчим компонентом електромобіля. Тому розробка методів виробництва, спрямованих на збільшення терміну його експлуатації, є актуальним завданням.

Проведено урахування механічних характеристик анізотропного матеріалу під час виготовлення посилених контейнерів для корпусів електричних елементів. Визначено дані, які достовірно відображають вплив коефіцієнта розтягування, площинної анізотропії та початкового діаметра заготовки на критичну товщину її пластини. Отримано вираз, який враховує всі характеристики технологічного процесу, що впливають на товщину початкової заготовки. Це дозволяє контролювати ці характеристики з метою оптимізації товщини заготовки. Отримана в результаті дослідження залежність дозволяє точно та якісно розрахувати оптимальну товщину вихідної заготовки на етапі розробки технологічного процесу виготовлення корпусів акумуляторних елементів для електромобілів.

Ключові слова: електромобіль, літій-іонний акумулятор, захист акумулятора, анізотропні матеріали.

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