Improving of closed die-forging of transport and marine fasteners “wing nut”

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Abstracts. The “wing nut” is a widespread transport and ship fixture designed to locking of hatches, covers and portholes. A more advanced closed die forging for the “wing nut” forgings of transport fittings was proposed with preforming by new method of bulk buckling of billet with upsetting ratio (height to diameter ratio) of 4.2...4.4. The billet and process calculation were performed based on results of researched and a new die forging was tested on a screw friction press. The results of experimental studies conducted on model lead billets at room temperature, and steel billets heated to 1180 °C, confirmed the increase in the accuracy rate of the billet material utilization ratio (one forging mass to one billet mass ratio) from 0.519 to 0.734 and metal savings up to 41% in comparison with the basic die forging without preforming of billet. It is shown that the introduction of a preforming by bulk buckling operation improves the forgings macrostructure (grainflow) even for cases the initial billets are buckled to folding defect formation, because with the further finishing die forging of semi-finished work-pieces the folding defect is displacing (or extruding) into flash. The improved die forging process and recommendations are accepted for implementation in the industry and the direction of reducing the cost of repair work for transport is noted.

1. Introduction
A wing nut ("wing-nut", “ears-nut” or “butterfly-nut”) is used for quick assembly-disassembly of parts of various machines, mechanisms, equipment that require frequent audits [1]. Areas of use of the “wing nut” in transport are replacement parts of tanks and cars; railway and marine fasteners, ship and railway (locomotive) fixture as winged fastener; gearboxes of cars and machinery, battery box; locking fixture of go-down hatches, boatborne, cabin and deck casement portholes windows, ship covers; manways, designing and building railway baseboards; air filters of trucks and tractors. Despite the U-sections (as wings, bows, shackles, clevises, U-clips, U-clamps etc.) that make up the bended line, the forgings for this parts produced by flat closed die forging on the press equipment. In this case, screw and crank presses are used, with various types of drives [2], including one with the possibility of electrical control of the actuator kinematics [3, 4]. For the forming of U-sections, complex extrusion methods [5, 6] and split extrusion dies [7, 8] are used, however, these methods complicate the kinematics of the tool even more and are economically justified only when producing a large series of “wing nut” forgings, which happens rarely. Given the working environment of products, such forgings are made not only of carbon steel, including coated, but also of non-ferrous metals and alloys [9].
To reduce the cost of the manufacturing process and its adaptation to any universal press equipment with simplification of the die tool, a new operation of billets preforming for open and closed die forging of forgings with a bent axis was proposed [10–12]. It is based on preforming by bulk buckling, which occurs during upsetting of billets with a height (or length) to diameter ratio (upsetting ratio) more than 3.5...4.0, which was not previously used even at upsetting with dies with different working faces [7, 13–15]. The complex stress-strain state of the work-pieces is subjected to detailed study [6, 7, 16], and the shape of the bent semi-finished product is predicted by varying of sizes of the billet \( (L_0 \text{ and } D_0 \text{ – initial billet length and diameter, i.e. upsetting ratio } L_0/D_0) \) and upset reduction (in engineering strain type) \( \varepsilon_u = 100(L_0 - H)/L_0 \), where \( H \) – the final height of the work-piece after pre-upset with buckling (distance between the top and bottom faces of flat dies) [11, 12, 17]; as well as by applying an intensifying inhomogeneous temperature fields [18–23]. The billet gets a bent with a thickening in the middle of the U-section. At the same time, there remains the risk of the forming of a “folder” defect [24–26], which should be avoided, and it is important to evaluate its displacement into the flash in case it appears for a specific forgings.

2. Materials and methodology

Closed die forging of “wing nut” forgings with an assortment of 0.2...0.5 kg under production conditions was considered, which is carried out by flat forging on screw press friction press with a nominal force of 1.6 MN from a round or square cross-section billets without preforming. The disadvantage is the low material utilization ratio \( (R_{mu} = 0.2...0.6) \), defined in this case as the ratio of the one finished forged part mass (after trimming) to the one initial billet mass \( [27–30] \). The material used is carbon and structural steels St3sp grade (analogs – S235, Fe37-3FN, Fe37-3FU: C=0.14...0.22%, Si=0.15...0.3%, Mn=0.4...0.65%, Ni<0.3%, S<0.05%, P<0.04, Fe~97%) and Grade 20 (analogs – C20E2C, C22, C22E: C=0.17...0.24%, Si=0.17...0.37%, Mn=0.35...0.65%, Ni<0.25%, S<0.04%, P<0.04, Fe~98%), etc. Therefore, the flash trimming is performed cold. Fig. 1 shows the initial single-stage closed die process without preforming for the “wing nut” forging-part weighing 0.21 kg \( (R_{mu} = 0.519) \).

Laboratory-and-industrial test die forging of the above mentioned “wing nut” forgings were carried out according to the initial and advanced process with using bulk buckling upsetting as a preforming stage. Automated calculations of billet dimensions \( (L_0 \text{ and } D_0) \) and upset reduction \( (\varepsilon_u) \) value for the new preforming operation were performed using the software (“Calcblank”) written according to the results of preliminary researches [10–12, 18]. Previously, after plotting of mass (volume) distribution diagram (ideal perform, cross-sectional areas) for the unbended-form of “wing nut” forging, initial data for the calculation were determined: volume of mass distribution diagram equal to volume of ideal preform as edged-fullered billet \( (V_t = 36000 \text{ mm}^3) \), average diameter of ideal preform \( (D_e,av = 23.7 \text{ mm}) \), minimum diameter of ideal preform \( (D_e,\text{min} = 16.7 \text{ mm}) \), maximum diameter of ideal preform \( (D_e,\text{max} = 33.4 \text{ mm}) \), length of ideal preform \( (L_e = 95 \text{ mm}) \), central bend angle between the U-section edges \( (\varphi = 120^\circ) \), final height of billet after upsetting with bulk buckling \( (H = 86 \text{ mm}) \), overall bend (deflection) of billet \( (B = 40 \text{ mm}) \), inner radius \( (r_i) \) – not limited for flat closed die forging in straight parting line dies.

The obtained results of calculations of billet dimensions from rolled steel round bar stock: length of the billet – \( L_0 = 98 \text{ mm} \), diameter of the billet – \( D_0 = 23 \text{ mm} \), upset reduction – \( \varepsilon_u \approx 30\%. \)

Die forging was carried out on a screw friction press F-1228 model with a force of 0.63 MN. Industrial dies with for flat closed die forging with straight parting line were used (Fig. 2). Preforming by upsetting with bulk-buckling was previously performed on a K116G crank press with a force of 0.63 MN. Both lead samples and St.3sp billets, which were heated to 1180 °C before deformation, were used; initial sizes of billets for preforming to die forging: \( \varnothing 23\times98 \text{ mm} \) and \( \varnothing 22\times96 \text{ mm} \) (additional experimental billets).
Figure 1. Initial process of wing nut closed die forging (billet Ø30 mm × 73 mm, material – St3sp).

Figure 2. Industrial dies for “wing nut” forging.

As a result of laboratory-and-industrial die forging, the possibility of using steel billets with \( L_0 = 96 \text{ mm}, \ D_0 = 22 \text{ mm} \) and \( \varepsilon_u = 34\% \) was revealed, which gives additional metal savings (\( R_{mu} \) increases to 0.734). Based on the fulfilled research the relevant adjustments were made to the “Calcblank” software.

3. Results and discussion

A comparison of the stages of experimental die forging from lead billets according to the initial (Fig. 3(a)) and the advanced (Fig. 3(b)) process shows a significant reduction in the size of the flash. The die forging of an experimental series of “wing nut” forgings from steel (St3sp) billets using the advanced process (Fig. 4) confirmed metal savings of 26.7% with \( \text{Ø} 23 \text{ mm} \times 98 \text{ mm} \) billet and 41.4% with \( \text{Ø} 22 \text{ mm} \times 96 \text{ mm} \) billet compared to the initial factory technology.

Figure 3. Stages of experimental “wing nut” forging according to the initial (a) and advanced (b) process (material – antimonial lead).

Preforming of billets with upsetting up to 29% (\( \varepsilon_u < 29\% \)), leads to a significant non-filling of the middle of the die cavity (\( D_{max} \) section) at the finishing die forging. Upsetting of billets over 36% (\( \varepsilon_u > 36\% \)) is accompanied by underfilling of the remote wings sections at finishing die forging and poor centering of the preformed semi-finished workpiece in the die impression (probable ”off-center strike” or ”mint-made error” defects). The using of billets with \( D_0 > 23 \text{ mm} \) or with \( D_0 < 22 \text{ mm} \) is not rational, because it is accompanied by a general increase of the flash volume or underfilling of the die cavity, respectively.
Figure 4. Wing nut die forging by advanced technology with preforming of billets by bulk buckling (material – steel St3sp).

It is known, approximating of the billet shape to the forging configuration improves the fibrous macrostructure (grain flow) of metal. In order to compare the grain flows, macrosections of the (in the plane of the dies parting line) forgings formed by the initial and new advanced process were made. In the macrosections (Fig. 5) it can be seen that the wing nut, die forged according to the advanced process including preforming of billed by bulk buckling, see Fig. 5(b), has a more pronounced fibrous grain flow lines compared wing nut obtained by the initial process (see Fig. 5(a)).

Figure 5. Macrosections with grain flow of “wing nut” forgings forged according to initial (a) and advanced (b) process.

Figure 6. Macrosection with grain flow of the “wing nut” forging forged from a preformed work-piece with a formed “folder”, pre-upset to \( \varepsilon_u = 50\% \) (excess of \( \varepsilon_{u,max} \) by 9.5\%, were \( \varepsilon_{u,max} \) – upset reduction at which the “folder” defect begins).

Results showing the benefits of advanced process are summarized in table 1.

|                           | Initial process (without performing) | Advanced process (with performing) | Advantage |
|---------------------------|-------------------------------------|-----------------------------------|-----------|
| “Wing nut” forging mass   | 0.21 kg                             | 0.21 kg                           | -         |
| Billet dimensions         | \( \varnothing 30 \text{ mm} \times 73 \text{ mm} \) | \( \varnothing 22 \text{ mm} \times 96 \text{ mm} \) | +         |
| Billet mass               | 0.406 kg                           | 0.286 kg                          | +         |
| Material utilization ratio| 0.519                               | 0.734                             | 41.4\%    |
| Number of forging stages  | 1                                   | 2                                 | -         |
| Grain flow                | Pronounced                          | Good pronounced                   | +         |

When die forging according to the recommended advanced process, there is no “folder” defect and fibers cutting along the perimeter of the flash is less than in the initial technology. The shaded sections in the area of the connection between the forging wings and its nut-head are the areas of maximum strains (accumulation of dislocations), which indicates the better metal processing. Consequently, the best performance characteristics of parts obtained from forgings produced according to upsetting with bulk buckling process as preforming of billets for closed or impression die forging are obvious. When flat die forging in dies with a straight parting line, it becomes possible to use preformed work-piece pre-upseted to \( \varepsilon_u > \varepsilon_{u,max} \), because the “folder” defect is extruded into the flash. The absence of a defect
is confirmed by grain flow in macrosection from steel forging, die forged from pre-upset buckled billet as preform with a formed “folder” (Fig. 6).

Due to the excess of $\varepsilon_u$ value recommended for bulk buckling preforming processes (see above), the filling of the forging's wings is incomplete. However, according to Fig. 5 and Fig. 6, it is seen that an increase in $\varepsilon_u$ value during preforming improves the useful grain flow lines structure (as fibrous macrostructure) of a forging. The results of the conducted research in the form of a new technology for die forging of “wing nut” forgings are accepted for implementation in manufacture.

4. Conclusion
For the manufacturing of transport an marine fasteners “wing nut” a more advanced die forging process included pre-upsetting with bulk buckling of high billets with upsetting ratio (height to diameter ratio) of 4.2...4.4 was proposed. Pre-obtained buckled preform more accurately fits into the die impression shape. Based on the research results and using the early designed software, calculations were performed, and a new process of die forging was tested on a screw friction press. The results of experimental research on model lead billets at room temperature and steel billets heated to 1180 °C has confirm an increase in material utilization ratio ($R_{bmu}$) from 0.519 to 0.734 and metal savings up to 41% in comparison with the initial process without preforming. It was shown that the introduction of a preforming operation improves the grain structure of forgings even for cases when the work-pieces are buckled to the formation of folding defect. With further closed die forging of preformed work-piece, the "folder" defect is displaced (extruded) into the flash. An increase in the number of die forging stages by one is not a significant drawback in small series manufacturing. The improved technological process and recommendations are accepted for implementation in the manufacture. Obviously, reducing the cost of transport and marine fasteners will lead to a decrease in the cost of repairs works.

References
[1] Henriksen E K 1973 Jig and fixture design manual (New York: Industrial Press)
[2] Yavtushenko A V 1982 Soviet engineering research 2(5) 35
[3] Yarymbash D, Kotsur M, Yarymbash S and Kylymyuk I 2018 IEEE 3rd International Conference on Intelligent Energy and Power Systems (IEPS), Kharkiv
[4] [4] Podnebennaya S K, Burlaka V V and Gulakov S V 2018 IEEE 3rd International Conference on Intelligent Energy and Power Systems (IEPS), Kharkiv
[5] Gerasimova A A, Gorbatyuk S and Efremov D 2020 Solid State Phenomena 299 513
[6] Tomov B 2007 Journal of Achievements in Materials and Manufacturing Engineering 24(1) 443
[7] Tschaetsch H 2006 Metal forming practise: processes—machines—tools (Berlin: Springer, Heidelberg)
[8] Peng Y and Zhao Z 2002 Int J Adv Manuf Technol 20 357
[9] Titov V A, Zlochevskaya N K, Kachan A Y, Savchinskii I G and Vishnevskii P S 2014 Metallurgist 58 141
[10] Kukhar V, Burko V, Prysiazhnyi A, Balalayeva E and Nahnibeda M 2016 East-European Journal of Enterprise Technology 3(7)(81) 53
[11] Kukhar V, Balalayeva E, Prysiazhnyi A, Vasylevskyi O and Marchenko I 2018 MATEC Web of Conferences 178 02003
[12] Kukhar V, Artiukh V, Prysiazhnyi A and Pustovgar A 2018 E3S Web Conf. 33 02031
[13] Markov O, Zlygoriev V, Gerasimenko O, Hrudkina N and Shevtsov S 2018 Eastern-European Journal of Enterprise Technologies 5(1)(95) 16
[14] Artiukh V, Kukhar V and Balalayeva E 2018 MATEC Web of Conferences 224 01036
[15] Weroński W S, Gontarz A and Pater Z 2006 Journal of Achievements in Materials and Manufacturing Engineering 17(1-2) 409
[16] Ogorodnikov V A, Dereven’ko I A and Sivak R I 2018 Mater Sci 54 326
[17] Osadchii V A, Gorbatyuk S M, Filippov D I and Kuprienko N S 2019 Metallurgist 63 658
[18] Kukhar V, Artiukh V, Serduik O and Balalayeva E 2016 Procedia Engineering 165 1693
[19] Anishchenko A, Kukhar V, Artiukh V and Arkhipova O 2018 MATEC Web of Conferences 239 06006
[20] Anishchenko O S, Kukhar V V, Grushko A V, Vishtak I V, Prysiazhnyi A H and Balalayeva E Yu 2019 Materials Science Forum 945 531
[21] Anishchenko A, Kukhar V, Artiukh V and Arkhipova O 2018 MATEC Web of Conferences 239 06007
[22] Aliiev I, Zhbankov Y and Martynov S 2016 Journal of Chemical Technology & Metallurgy 51(4) 393
[23] Efremenko V G, Zurnadzhi V I, Chabak Y G, Tsvetkova O V and Dzherenova A V 2017 Material Science 53 67
[24] Gao P F, Fei M Y, Yan X G, Wang S B, Li Y K, Xing L, Wei K, Zhan M, Zhou Z T and Keyim Z 2019 Journal of Manufacturing Processes 39 181
[25] Gao P, Yan X, Fei M, Zhan M and Li Y 2019 Int J Adv Manuf Technol 104 1603
[26] Thorat M L and Ligade R R 2018 International Journal of Scientific Development and Research (IJSDR) 3(4) 34
[27] Tomov B 2007 Journal of Achievements in Materials and Manufacturing Engineering 24(1) 443
[28] Peng Y and Zhao Z 2002 Int J Adv Manuf Technol 20 357
[29] Markov O E, Gerasimenko O V, Shapoval A A, Abdulov O R and Zhynikov R U 2019 International Journal of Advanced Manufacturing Technology 103(5-8) 3057
[30] Markov O, Gerasimenko O, Allieva L, Shapoval A and Kosilov M 2019 Eastern-European Journal of Enterprise Technologies 2(1)(98) 39