Constructive and technological modernization of the aircraft beam

Yu G Lyudmirsky\textsuperscript{1}, V V Shepkin\textsuperscript{1}, and S S Assaulenko\textsuperscript{1,2}

\textsuperscript{1}Don State Technical University, Gagarin sq., 1, Rostov on Don, 344003, Russia
E-mail: \textsuperscript{2}assaulenko\_s@mail.ru

Abstract. The directions of modernization of welded structures, previously created and serially produced in the aerospace, transport and other industries, are considered. For this, it is proposed to use thermally hardened aluminum alloys as the base metal, and to obtain permanent joints, instead of argon-arc welding, use friction stir welding (FSW), which is performed in the solid phase and has many advantages. Purpose of the work: to show the usefulness of constructive and technological modernization of previously designed and manufactured structures, taking into account the latest achievements in welding, in particular, when creating structures from aluminum alloys using FSW. An example of the modernization of an aircraft beam made of AMg6 aluminum alloy with the help of a FSW is given, which clearly demonstrates how the shape and geometry of the structure are interrelated with the technology of its manufacture. The presented structural and technological options for the modernization of the beam ensured: a decrease in welding stresses and deformations, an increase in the cyclic strength of a structure, savings in materials, labor, time and a decrease in the cost of manufactured products.

1. Introduction

The task of creating economical welded structures with the maximum use in them of all the best properties of the base metal and new capabilities of welding technology requires a revision of the design principles of the structures themselves and the technological processes of their manufacture [1-3].

The structure of the aircraft beam, shown in Figure 1, is made of 6mm thick AMg6 aluminum alloy.

The beam consists of left and right webs. Each of them, due to the small overall dimensions of the sheet blanks, has a butt seam performed by means of argon-arc welding by non-consumable electrode on the remaining lining. The linings are welded to the webs with fillet welds with a 6mm leg. One end of the beam is pinched, the other is acted upon by a force $P = 1000N$. The beam operates under repeated static loads.

The modernization of the manufacture of the beam using the FSW became possible as a result of the fact that All-Union standard 134-1051 was developed and approved for the rocket and space industry. It outlines the capabilities of FSW, the technology for its implementation and the requirements for quality control of products made of aluminum alloys. Friction stir welding performed in the solid phase, in comparison with fusion welding methods, has the following main advantages [4-10]:
Figure 1. Airplane beam: 1-left and right web; 2-lining; weld joint: №1 - Russian State Standard 14771-INp-H1, №2 - Russian State Standard 14771-INp-Y4- 6-50/100, №3 Russian State Standard 14771-INp-C19.

- in the welding zone, the properties of the base metal are practically preserved;
- joints have by 5-7 times lower level of residual stresses and deformations than when performing argon-arc welding;
- no filler materials and shielding gas are required;
- it is possible to increase the welding speed (3-4 times) without deteriorating the mechanical properties of the joints;
- FSW made weld joints have a lower residual welding stresses of 5-6 times compared to argon arc welding;
- electricity consumption is reduced by 2-3 times.

Purpose of the work: to show the usefulness of the structural and technological modernization of previously designed and manufactured structures, taking into account the latest achievements in welding, in particular, when creating structures from aluminum alloys using FSW.

2. Materials and methods
Friction stir welding creates various opportunities for improving quality, reducing labor intensity and cost of manufacturing products [4]. For example, in order to obtain the required length of the beam and ensure equal strength of the butt joint (see Figure 1) with the base metal, it can be performed with the FSW without the remaining lining. This reduces stress concentration and residual welding stresses, which should increase its fatigue strength. In addition, to improve the stress-strain state in the considered butt weld, it is advisable to move it closer to the acting force, as shown in Figure 2, which more than 4 times reduces the stresses in these welds a result of a decrease in the moment created by the force P (In the previously created construction, the moment is equal to 100kg*300cm=30000 kgh*sm, and in the upgraded design, the moment is equal to 100kg*65cm=6500 kgh*sm).
Figure 2. Beam structure and welded butt joints performed by FSW, weld joint: №1 - Russian Industry Standard 134-1051-FSW-C5, №2 - Russian State Standard 14771-INp-U4- 6-50/100. In this case, the elimination of the forming lining has reduced the cost of their manufacture, for the execution of their fastening welds, while the residual welding stresses, which usually negatively affect the fatigue strength of structures, have decreased. The joint work of designers and technologists led not only to improved production and economic performance, but also improved the performance of the beam.

To connect the left and right walls to each other, the project provided the processing of fillet welds by argon-arc welding. It should be noted that the processing of fillet welds by FSW meets certain difficulties. Figure 3 shows several options for obtaining high-quality fillet joints [11, 12, 13, 14, 15] performed by FSW.

Figure 3a shows a fillet joint when one of the parts has a thickness greater than half the diameter of the shoulders of the FSW tool. This allows quality corner joints to be obtained.

Figure 3. Options for obtaining high-quality corner joints FSW: a) - one of the parts has a thickness of more than half the diameter of the tool for FSW; b) - both parts are prepared for welding of corner welds, by local thickening of the edges; c) - the connection obtained by the FSW along the thickened edges.
Figures 3b and 3c show the design of a corner joint, for the implementation of which, first, by plastic deformation, it is necessary to thicken the edges (see Figure 3b), and then perform an FSW weld along the thickened edges. The disadvantage of such a connection is a significant increase in labor intensity and cost of obtaining corner joints.

Taking into account the difficulties in obtaining fillet welds of FSW, when modernizing the production of a beam, options were considered for replacing fillet joints with more technological for FSW - butt joints. In addition, it should be noted that butt joints tend to have a higher load-bearing capacity than corner joints.

Figure 4 shows the considered options for manufacturing a beam by making butt welds of STP.

Figure 4a shows the design of a beam, in which rolled products are used in the form of an angle and flanges and walls are welded to it with butt welds. It was done to obtain the required geometry. This is a very convenient and reliable way to produce box beams, but it requires six butt welds instead of two fillet welds. However, if we weigh all the advantages of FSW in comparison with argon-arc welding and take into account the absence of bending operations, rather long elements (3675 mm), then the option under consideration is worth our attention.

Figures 4b and 4c show two options for obtaining the required beam geometry by making two butt welds for connecting bent elements.

![Figure 4](image)

**Figure 4.** Variants of manufacturing a FSW box beam by making butt welds: a - in the corners of the beam is a rolled product in the form of isosceles or unequal corners; b and c - options for obtaining a beam from the bent elements; d - the option of obtaining a beam from profile channels.

It should be noted that when performing a beam according to option 4b and 4c, the welds are practically not loaded, which will provide a high bearing capacity of the beam, which will mainly be limited by the strength of the base metal.

Figure 4d shows the structure of a box-shaped beam assembled from two profile channels welded with butt welds. Its advantage is the absence of bending operations. To ensure high quality of the beams, the connected flanges of the channels before the FSW must be machined.

The given example of the modernization of the manufacture of an aircraft beam made of the AMg6 aluminum alloy using the FSW clearly demonstrates how the shape and geometry of the structure are interconnected with the technology of its manufacture. The presented structural and technological options for modernization of the beam provide: reduction of welding stresses and deformations, increase in cyclic strength, savings in materials, labor, time and a decrease in the cost of manufactured products.
3. Discussion and conclusions
1. Structural and technological modernization of the beam made it possible to reduce the cost of manufactured products due to:

- saving of materials, labor and time for the manufacturing of the beam;
- rational arrangement of welds with respect to existing loads;
- replacement of fillet welds with butt welds;
- reducing the number of welds and their length;

2. Replacement of automatic argon-arc welding with non-consumable electrode for friction stir welding allows to increase both static and re-static strength of the beam.

References
[1] Lyudmirsky Y, Assaulenko S 2018 Vestnik of DSTU, Vol 3, pp 311-317
https://doi.org/10.23947/1992-5980-2018-18-3-311-317
[2] Cooper D R, Julian M. Allwood J 2014 Mater. Process. Tech., Vol 214, pp 2576-2592
[3] RajKumar V, Venkatesh Kannan M, Sadeesh P, Arivazhagan N, Devendranath K 2014 Ramkumar Procedia Eng., Vol 75, pp 93-97
[4] Huang Y, Wang Y, Wan L, Liu H, Shen J, dos Santos J F 2016 Int J Adv Manuf Technol, Vol 87, pp 1115-1123
[5] Zhou L, Li G H, Zha G D, Shu F Y, Liu H J, Feng J C 2018 Sci Technol Weld Join, Vol 23, pp 596-605
[6] Zhang J, Feng X S, Gao J S, Huang H, Ma Z Q, Guo L J 2018 J Mater Sci Technol, Vol 34, pp 219-227
[7] Wan L, Huang Y, Guo W, Lv S, Feng J 2014 J Mater Sci Technol, Vol 30, pp 1243-1250
[8] Brassington W D P, Colegrove P A 2017 Sci Technol Weld Join, Vol 22, pp 300-318
[9] Rai R, De A, Bhadeshia H K D H, DebRoy T 2011 Sci Technol Weld Join, Vol 16, pp 325-342
[10] Sun T, Roy M J, Strong D, Withers P J, Prangnell P B 2017 J Mater Process Tech, Vol 242, pp 92-100
[11] Sun T, Tremsin A S, Roy M J, Hofmann M, Prangnell P B, Withers P J 2018 Mater Sci Eng A, Vol 712, pp 531-538
[12] Zhang H, Wang M, Zhou W, Zhang X, Zhu Z, Yu T 2015 Mater Des, Vol 86, pp 379-387
[13] Guan M, Wang Y, Huang Y, Liu X, Meng X, Xie Y 2019 Mater Lett, Vol 255, Article 126506
[14] Zhang Y N, Cao X, Larose S, Wanjara P 2012 Can Metall Q, Vol 51, pp 250-261
[15] Maggiolini E, Tovo R, Susmel L, James M N, Hattingh D G 2016 Int J Fatigue, Vol 92, pp 478-487