Modeling of the stress-strain state for a disk and a shaft from different Ni-based alloys during welding under shear pressing

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Abstract. The stress-strain state in a disk and a shaft made of different heat-resistant Ni-based alloys during pressure welding is analyzed by the finite element method. The disk and the shaft have a complimentary cone shape, and during welding the shaft is inserted into the disk or inserted and simultaneously rotated. In the first case, a single component shear deformation is realized, while in the second case, one has a two-component shear deformation in the welding zone. The cone angle of 5° can be recommended, because in this case the plastic deformation in the welding zone is about 3%, which is typically sufficient for obtaining a reliable joint.

1. Introduction
Improving the manufacturing technology of rotor structures designed for the 5th generation gas turbine engine is a very important problem [1-16]. The use of bimetallic parts, such as blisk, disk–disk and disk–shaft, made of heat-resistant nickel and titanium alloys, reduces the weight of the engine. Of particular interest for the engine is a disk fixed on the turbine shaft. When creating such units, it is necessary to ensure a reliable connection between the welded surfaces, since the presence of defects in the weld of such structures can lead not only to the destruction of the part, but also to the destruction of the entire engine. Pressure welding (PW) is widely used to obtain permanent joints in such structures. In the process of PW, a solid-phase joining takes place under the relatively small applied pressure between the parts being welded, which provides plastic deformation of the contact surfaces and stimulates diffusion processes. This approach has several advantages, e.g., it is easy to execute, it allows welding of similar materials and materials with very different properties, it allows controlling the structure and properties of the joint. However, this method should be applied with caution, because in some cases the joining can be accompanied by significant pore formation, which leads to heterogeneity of the welded joint and to the deterioration of the quality of welding. To avoid such drawbacks, a combined PW can be used, in which together with pressing, the shear deformation is present in the welding zone. The application of shear during welding helps to increase plastic deformation in the layer close to the surfaces to be welded and does not affect strongly the rest of the material, which is very important for such parts of the aircraft engine as disks and shafts.

In this paper, we consider the method for producing a welded joint by PW, carried out by inserting and/or rotating a shaft in contact with a disk. With the help of finite element simulation, the stress-strain state in the disk and the shaft from the heat-resistant nickel-base alloys EP975 and EK79 is in-

vestigated with the aim to estimate the magnitude of shear deformation at the contact surface. It is well known that shear deformation in the welding zone improves the quality of welding.

2. Finite element model

Computer simulation is performed using the DEFORM-2D software package. Pressure welding of the shaft and the disk is modeled in the axisymmetric setting. A schematic view of the disk and the shaft is presented in figure 1 a. Different forms of the shaft and the disk are considered. The shaft is a cylinder with a diameter of 12 mm and a height of 12 mm, coupled with a truncated cone with a height of 20 mm having the angle 0°, 0.5° or 5°. In the case of a cone angle of 0°, the shaft has a simple cylindrical shape. The hole in the disk has a narrowing with the same cone angle as that of the shaft, so that the shaft and the disk have complimentary shapes. The disk height is 14 mm and the diameter is 28 mm.
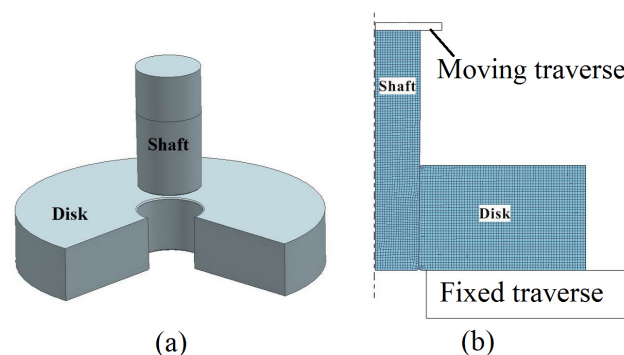

Figure 1. (a) Schematic view of the disk and shaft of a gas turbine engine. Part of the disc is removed for clarity. (b) Finite element model of the shaft and the disk. The disk lies on a fixed traverse, and the shaft is inserted in the disk with or without rotation about its axis.

The finite element model is shown in figure 1 b. When conducting computer simulation, the deforming tool (the upper moving traverse) and the supporting body (the lower fixed traverse) have the properties of an absolutely rigid body. The deformable bodies (the disk and the shaft) are assumed to be elastic-plastic. The disk and the shaft are made of the ultrafine-grained superalloys EP975 and EK79, respectively. The material properties were determined by experimental stress-strain curves obtained under uniaxial compression of the alloys at the welding temperature. Welding was carried out in isothermal conditions at a temperature of 1100 °C.

Deformable bodies were divided into twenty-node isoparametric finite elements with a quadratic approximation of the displacement fields. The number of elements is 2500 for the disk and 1700 for the shaft. For welding, the disk was mounted on a fixed traverse and the conical part of the shaft was placed into the disk hole. Contact conditions at the boundaries of the traverse-shaft and the disk-shaft pairs are described by the Ziebel friction model. The value of the friction coefficient is assumed to be 0.3. The deformation of the shaft and the disk in the course of PW, carried out during the insertion and/or rotation of the shaft in contact with the disk, was simulated. Two different loading schemes are considered:

Scheme 1: the shaft is inserted into the disk by the motion of the upper traverse down by 3 mm with the strain rate of 10^{-3} s^{-1};

Scheme 2: a combination of the insertion of the shaft into the disk and simultaneous rotation of the shaft about the z axis. The shaft is inserted into the disc by 3 mm with a strain rate of 10^{-3} s^{-1} and rotates with a speed of 3 rpm.

3. Simulation results

When analyzing the results of computer simulation, the distribution of the shear deformation is considered, since the normal deformation components have little effect on the quality of the welded joint.

The simulations show that, in welding according to Scheme 1, a single component of shear deformation prevails, which is ε_{rz}, while $\varepsilon_{r\theta}$ is much smaller. In this case one can speak of a one-component shear deformation. On the other hand, welding according to Scheme 2 results in both shear deformation components, ε_{rz} and $\varepsilon_{r\theta}$, to be comparable, i.e., a two-component shear deformation takes place in this case.

The distribution of ε_{rz} in the disk and the shaft after welding according to Scheme 1 is shown in Figure 2 for the cone angle a) 0°, b) 0.5°, and c) 5°. It can be seen that shear deformations in the contact zone increase with an increase in the cone angle. In the cases shown in b) and c) the shear deformation is distributed more evenly, while in a) it is concentrated close to the upper and lower surfaces of the disk. The maximum values of ε_{rz} increase with increasing cone angle. In b) they are 10 times greater than in a) and in c) 100 times greater than in a).

The distribution of ε_{rz} and $\varepsilon_{r\theta}$ in the disk and the shaft at the end of welding according to Scheme 2 are presented in figure 3 and 4, respectively. Both components of shear deformation are of the same order of magnitude in this case. The component ε_{rz} is distributed similarly to the case of Scheme 1. The distribution of $\varepsilon_{r\theta}$ is somewhat different from the distribution of ε_{rz}, but in both cases shear deformation is localized in the welding zone. As the cone angle increases, the maximum values of shear deformation also increase similarly to the case of Scheme 1. The area of maximum values with increasing angle of the shaft is distributed more evenly in the Scheme 2.
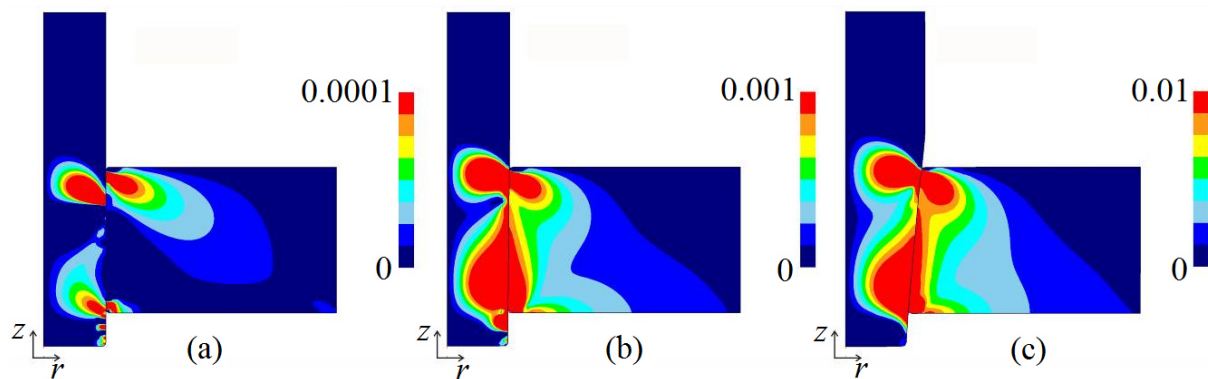

Figure 2. Distribution of shear strain ε_{rz} in the shaft and disk deformed according to Scheme 1 for the taper angle: a) 0°, b) 0.5°, and c) 5°. Shear strain $\varepsilon_{r\theta}$ is nearly zero in this case.
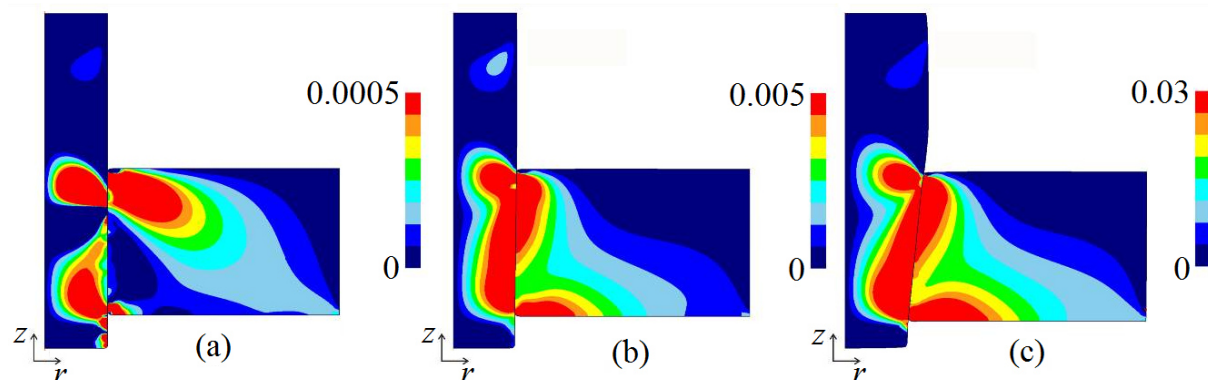

Figure 3. Distribution of shear strain ε_{rz} in the shaft and the disk deformed according to Scheme 2 for the taper angle: a) 0°, b) 0.5°, and c) 5°.
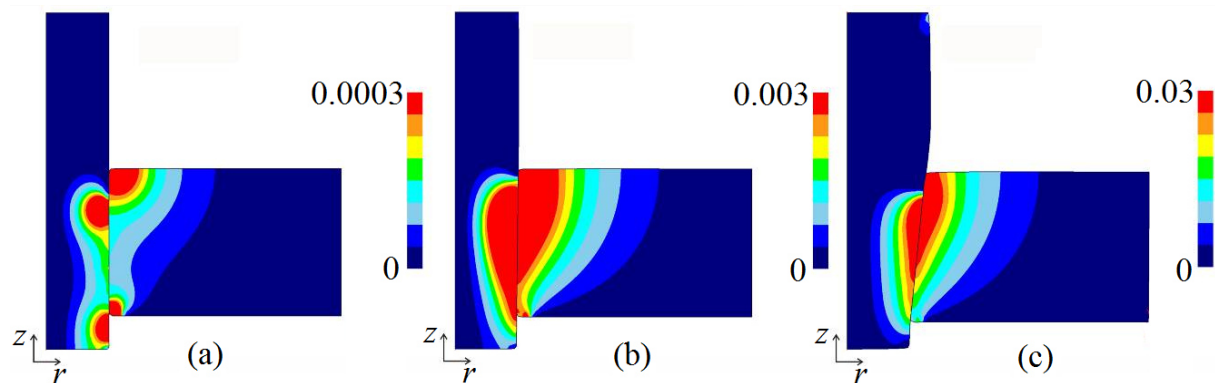
Figure 4. Distribution of shear strain $\varepsilon_{r\theta}$ in the shaft and the disk deformed according to Scheme 2 for the taper angle: a) 0°, b) 0.5°, and c) 5°.

4. Conclusions

In our work we came to the following conclusions:

1) To create a permanent connection between the disk and the shaft, it is preferable to use pressure welding, which is carried out with a combination of insertion and rotation of the shaft in the disk. In this case, a two-component shear deformation is provided, which, as is well known, improves the quality of the welded joint.

2) To improve the quality of the welded joint, the shaft and the disk should have a complimentary cone shape. The cone angle of 0.5° seems to be too small because it produces only 0.3% of shear strain. The angle of about 5° can be recommended because in this case the plastic shear deformation of about 3% is achieved, which is typically sufficient for obtaining a reliable joint.

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