Fatigue Strength of Blade with Disk Joints, Obtained by Linear Friction Welding

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Abstract. Fatigue tests of blisk welded sections is described. The bimetal blisk contains VT6 alloy (Ti6Al4V) blades and VT8-1 alloy (Ti6.5Al3.5Mo1.2Sn1.2Zr0.2Si) disc, joined by linear friction welding. The test results indicate that the combination of materials VT6 + VT8-1 can be used for bladed disks manufacturing, and technological factors, including availability of weld does not have a decisive influence on the fatigue strength of the investigated structure.

Introduction
Modern gas turbine engines have a wide application of blisks instead of constructions with mechanical fastening blades to discs. Now, Russian industry has mastered technology of manufacturing bladed disks from solid billets. However, with increasing height blades increases processing time and falls material utilization rate. In addition, this technology prevents the receipt of structures in which the disk and blades are made of different materials. Listed shortcomings can be remedied by the introduction of welds in the blisks design. Currently, the only method used industrially manufacture of welded blisks is linear friction welding (LFW). Linear friction welding is a type of friction welding with reciprocating movement of the parts used in foreign aircraft building industry since the early 2000’s, and mastering the domestic industry currently.

In existing modular compressor stages a combination of alloys VT8-1 (as the disk material) and VT6 (the blades) is quite often used. This combination is promising also such joint has high rates of static strength and toughness [1, 2], however, for application of welding technology in aviation engines the welded parts fatigue strength need to be evaluated [4-11].

The methodology of experimental research
As the object of study engine PD-14 II stage high pressure compressor blisk was chosen. The original version of blisk made from alloy VT8-1, was amended on welded structure. Disc material was kept unchanged, blades material was changed to VT6 alloy. Welded blades have height 48 mm, length of the chord in the plane of the weld interface was 53 mm, radius transition from shoulder blade to disk was 2 mm.

Samples (blisk sections) are represented at figure 1: left photo - after welding, right photo - after machining. For tests 21 samples in 2 batches were made. In the first batch, the blades manufacturing
alloy VT6 in structural state has been used, it’s traditionally used for making GTE blades. Second blades batch was made from VT6 alloy in ultra fine-grained condition.

Fig. 1. Blisk section:
left–after the welding; right–after the final machining.

Bladed disk sections from the first batch were annealed, and then hammered by 2 mm diameter steel balls. Fatigue tests were conducted with transverse bend under the influence of inertial loads using electrodynamic vibro-stands. The study of the samples included the search for cracks by the method of capillary flaw detection and their fractographic investigation.

Results and discussion

It was determined, that the fatigue crack in all cases is formed on the transition radius from blades to the disk. Analysis of macro- and microstructure, microhardness measurement revealed that metal structure in cracked areas corresponds to the original structure of the alloy VT8-1. Here is no thermal or mechanical affect of welding on metal structure in the fracture zone. Cracks in the first installment were at input and output edges (fig. 2). Fractographic study revealed inferior quality of machining the transition radius from blades to the disk (fig. 3), the presence of scratches and facets.

Based on the results obtained, before the fatigue test the second installment, was held an additional polishing of input and output edges, as well implantation of sections by nitrogen ions. The measures taken have made it possible to exclude the destruction of samples from the second installment on edges – the fracture was displaced on the back of the blade (fig. 4). Despite this, it is easy to see that the endurance curve for the samples from the second batch is lower than for the first batch. Available number of samples was insufficient to determine $\sigma_{-1}$, as for the first installment and for the second. However, from the information provided on the fig.5, you can see that we should expect the value of fatigue limit of sections of the first batch of about 255 MPa, and slightly lower for sections of the second installment.
Fig. 2. The location of the weld seam relative to the crack, identified by etching (for 1st batch).

Fig. 3. The fractogram of the sample from the first batch.
Reducing of fatigue strength, despite the improvement of the quality of the surface, may be triggered by few causes.

Heat treatment was excluded from technological process of second installment manufacturing because of heightened sensitivity to heating of ultrafine-grained microstructure. This could reduce endurance, since the cracking region is in the zone of action of tensile welding stress [3].
The obtained results can be related to difference between elastic properties of blades with ultra fine-grained and traditional condition – for the same deformation amplitude, the frequency of loading for a second batch were on average 6% higher.

Conclusions

Clear localization of fractures on samples with differing technology mechanical, heat treatment and surface hardening, indicates that from a list of factors (constructional features, microstructural condition of the blades, the thermo-mechanical effects of welding, machining quality, technology of heat treatment and surface hardening), the most significant factor is the concentration of stresses in the transitional radius from blades to disk.

Location of fatigue cracks showed that the welds are less dangerous than the stress concentrators already exists in the blisk structure, and so linear friction welding can be used for blisk manufacturing in gas turbine engines.

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