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Development of the Design and Technological Solutions for Manufacturing of Turbine Blisks by HIP Bonding of the PM Disks with the Shrouded Blades

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Abstract. A bimetallic turbine blisk with shrouded blades had been designed in order to enhance the gas-dynamic and strength characteristics of the wheels of the gas turbine engines and reduce their weight. The separately cast nickel superalloy shrouded blades are joined to disc made of the heat-resistant alloy powder using a method of hot isostatic pressing (HIP). The problem of such joint is complicated by the presence of the shrouds on the periphery of the blades. This design should provide a good contact on the working faces of the shrouds during the operation. In order to solve this problem, a capsule for manufacturing of the disk piece and a process flow diagram for calculation of shaping such a capsule during hot isostatic pressing have been developed.

Introduction

In various fields of technology, the need for high performance parts and components is constantly increasing. The shape and dimensions of blanks for such parts need to be close to the geometry of the final parts (the near net shape for the disk and net shape geometry for the blades). Traditional technology based on casting or forging and machining have serious limitations in the production of such blanks, due to the considerable difficulties in ensuring the requirements of geometrical complexity and required accuracy and distribution of performance and technological characteristics in the material.

The development of new technologies for the creation of bimetallic wheel structures, based on the processes of diffusion bonding of dissimilar alloys now allows us to meet the extremely high (and increasingly stringent) requirements for safe operation and economic efficiency of Gas Turbine Engines (GTE). Various methods are used to connect the blades to the disks; for example, electrochemical and mechanical methods of disk manufacture with blades from one forging, or blade connection to the disc by indentation at high temperature, soldering, friction welding, or hot isostatic pressing [1-4].

During the recent decades worldwide a progressive technological method based on Hot Isostatic Consolidation of rapidly solidified powders of advanced alloys into various shapes has been developed.

Hot isostatic pressing (HIP) of powder materials is a process of high-temperature consolidation of porous workpieces under a high pressure. This process eliminates the above-mentioned restrictions, allowing obtaining a workpiece of the required complex configuration. Such parts as impellers, diffusers, turbines are produced by hot isostatic pressing. Hot isostatic pressing is advantageous due to its ability to produce complex shape parts earlier available only by casting from difficult to process alloys, and possessing mechanical properties of the wrought materials.

In the variety of technological parameters influencing the final shape of the product the decisive one is the design of capsule as a deformable tool that determines the original shape of the workpiece and transmitted pressure. From the point of view of HIP, presence of a deformable capsule leads to a nonuniform stress in the powder material and the complex change of the bulk shape [5, 6].

The complication of process within a wide range of pressures and temperatures and the absence of rigid forming tool require constant analysis (forecasting the ultimate shape of the workpiece after HIP) and synthesis (designing capsules ensuring the desired shape and size). Further improvement of HIP technology is associated with an increase of quality and reliability aimed at effective manufacturing of parts with surfaces that do not require additional machining.

The requirements to the turbine wheel of a gas turbine engine

The wheel of a high-pressure turbine engine is a key component that defines the main engine characteristics. A reasonable approach to increasing the efficiency of turbine of such type is to use blade shrouding. However, this shrouding also increases the centrifugal loading on the profile part of the blades, the lock connection, and the disk.

The wheel elements of gas turbines operate under of non-uniform loading and radial heating. Hence, the materials for the different parts of the wheel should meet different requirements. Therefore, the wheel should combine the materials satisfying the required working conditions in the appropriate areas.

One area recognized as a stress concentrator is the lock connection of the blades with the disk. The stress at this location limits the life of the wheel, and its reinforcement results in an increased disk weight. Wheels with detachable blades often do not allow placing of the necessary number of blades from the point of view of gas-dynamic efficiency.

One solution of this problem is to eliminate the lock connections. The design of the wheel may take the form of a Bimetallic Blisk (BB), where the blades and the disk part are made of different materials and HIP bonded together [7 - 9]. Several blisks made of heterogeneous alloys for small turbines were designed in CIAM [10 - 14].

The shrouds are necessary for improved efficiency as they reduce the gas flow in the radial gap. In general, shrouds are designed for damping and detuning purposes, especially of long thin blades. These goals are achieved by designing the working wheels in such a way that they ensure both a reliable contact on the shroud working faces and an acceptable level of stress, especially in thin peripheral blade sections. The blades are assembled with interference between the working faces to ensure the contact between the blade shrouds [7].

The technological design of the turbine wheel should meet the following requirements:

- Reduction of the wheel mass,
- Increasing of the turbine wheel efficiency,
- Ensuring of reliable contact of the shroud working faces during operation,
- Meeting of strength and detuning requirements,
- The possibility of manufacturing.

The designed BB consists of heat resistant superalloy shrouded blades bonded to a nickel alloy powder disk. A single-stage wheel turbine for small-sized engine was designed with the goal of improving its efficiency. The blades of blisks were proposed to be made with shrouds in order to minimize the losses due to the radial clearance at the shroud (Fig. 1a).

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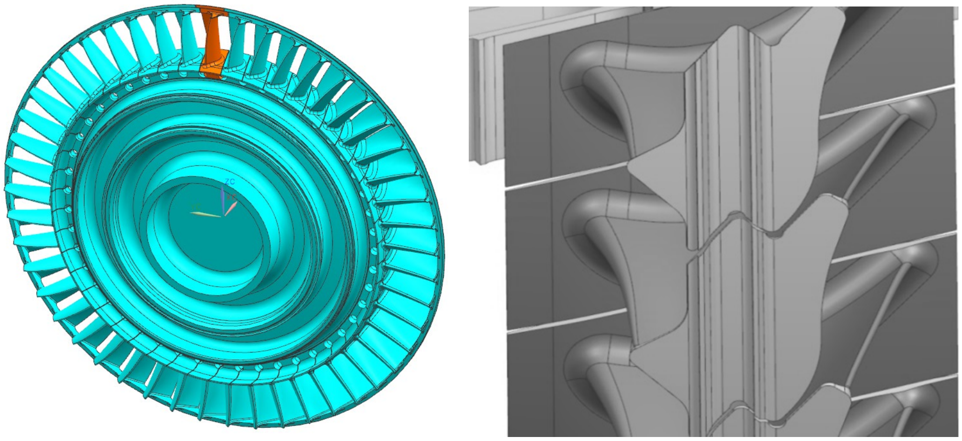

Figure 1. a)The project of BB with shrouds, b)The shrouds

The shroud construction is aimed at minimizing its weight and meets the above mentioned requirements. As calculation has shown, the efficiency of the turbine with shrouded blades is increased by 0.2% compared to that of a wheel without shroud.

The preliminary gap between the working edges of the shrouds (Fig. 1b) should be provided due to the peculiarities of the technological process of manufacturing blisks [8].

The location and configuration of the connection zone of the blade with the disc part are determined by the demand of minimization of weight of wheels and satisfaction of the requirements of strength under specified conditions of operation and capabilities of the production process.

The cross section of the shank of the blade is parallelogram shaped. Such shank is required to ensure the specified angles of the vanes in the gas channel (Fig. 2).

Initially the optimal position of the connection zone of the wheel is determined on the basis of equal strength of materials of the blades and disk part with respect to temperature in this area on the most damaged mode. Then the location of the connection zone is adjusted from the design considerations.

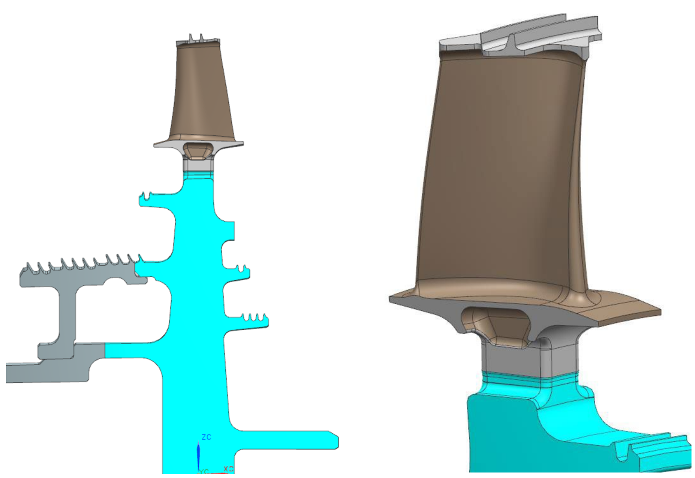

Figure 2. The connection zone of the blades with the disc part

The area of the connection zone is pre-determined by the satisfaction of requirements of safety for bearing capacity. On the basis of computation, the blisk turbine was designed with the weight reduced by ~10% compared to the original wheel design with a fir-tree connection.

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Technological aspects

Development of technological process of manufacturing BB turbine with shrouded blades includes the following steps:

- Development of sonic shape blanks for BB with the features of NDT methods (fig.3),

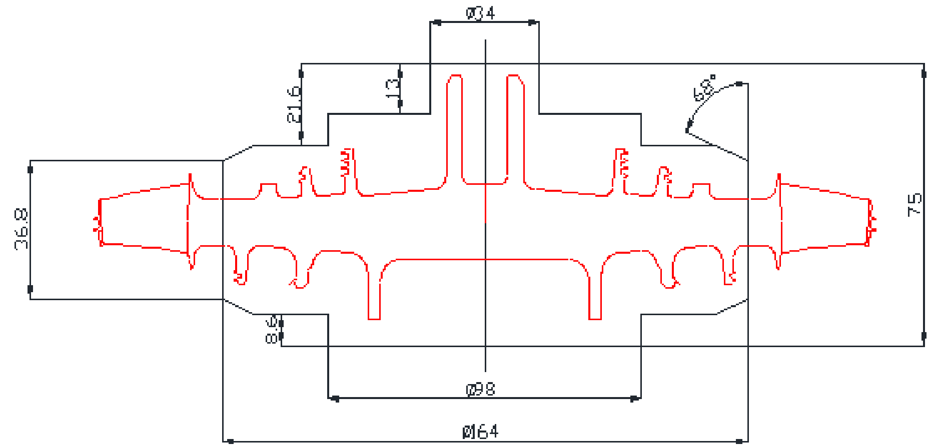

Figure 3. Sonic shape blanks for BB

- Designing of the HIP tool (Capsule) for the manufacture of the blank of the BB with shrouded blades,
- FEM Modeling of deformation of the capsule during the process of hot isostatic pressing,
- Development of the drawings for the capsule,
- Development of manufacturing technology for the capsule elements.

The problem of bonding the blades to the disc part to form a single part using the HIP method is as follows. The process of joining these components at high temperature and pressure is accompanied by the shrinkage of the powder disc alloy in the gap between the disc part and the blades. In this case the blades move in the direction of the disk. However, the blades cannot move if there is no clearance between the blade shrouds. In this case, good bonding of the shanks of the blades with the disc part is more difficult to achieve.

Allowing movement of the blades to the disk in the process of shrinkage of the powder requires the assembly of the blades in the capsule in a special fixture that provides gaps between the shrouds. The value of these gaps must be reduced to zero after successful completion of the connection of the blades with the disc.

For the manufacturing of Blisk by hot isostatic pressing, the workpiece forming simultaneous connection of hard disk and blade parts in the capsule filled with powder was itself a special forming tool (Fig. 4). The capsule was filled with powder material (in these case alloy EP 741NP). The cast alloy blades GS32 and shaping steel inserts are inside the capsule. Inserts that are consequently removed from the finished product leave the cavity of the desired shape. During HIP capsule undergoes uneven shrinkage, taking the form of the product. Precisely the complexity of modeling of shrinkage for this 3-dimensional object is the major difficulty in obtaining products of required geometry.

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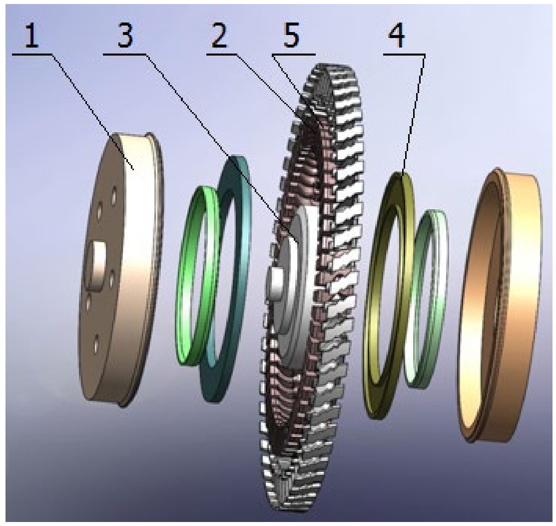
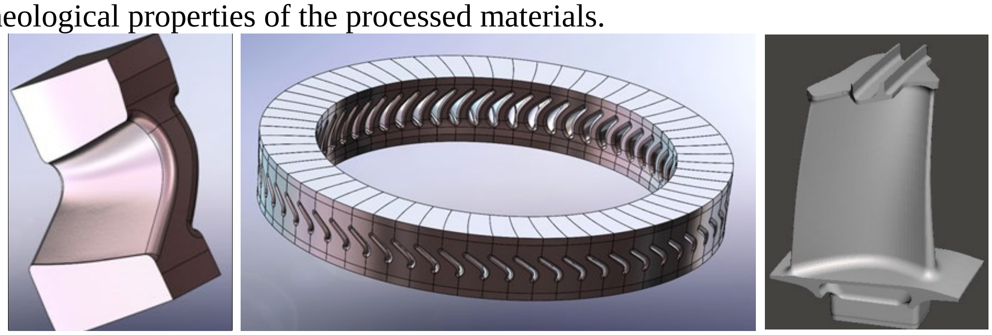
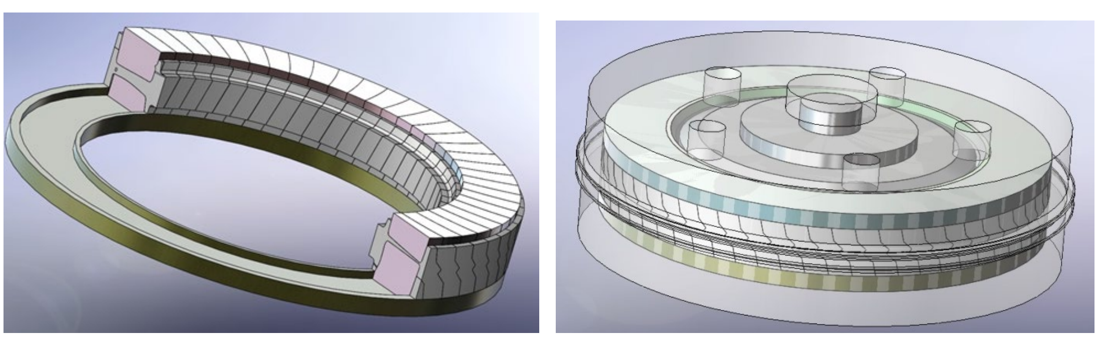


Figure 4. Capsule for forming a BB: 1-capsule, 2- inserts, 3-central part, 4-fixing elements, 5-cast blades

The task of the mathematical description of the process is to design the capsule and inserts in such a way that the final shape of the powdered products had the required geometry. The advantage of analytical descriptions is that it allows to more fully analyze the dependence of the required characteristics of the parameters of process. Since this task is physically and geometrically nonlinear, such precision is difficult to achieve: first, purely mathematical difficulties; secondly, the main difficulty is defining relations precisely describing the process and the rheological properties of the processed materials.



a) Inserts b) Cast blade



b) Cast blades and fittings d) Assembly

Figure 5. View of the individual capsule elements and their assembly

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In practice, the process of manufacturing of powder products is an iterative process, and its essence is as follows: construction of a mathematical model, capsule design based on this model, manufacturing of the product. The geometry of product is compared with the required, then basing on this mapping, the mathematical model is tuned and then the process is repeated again.

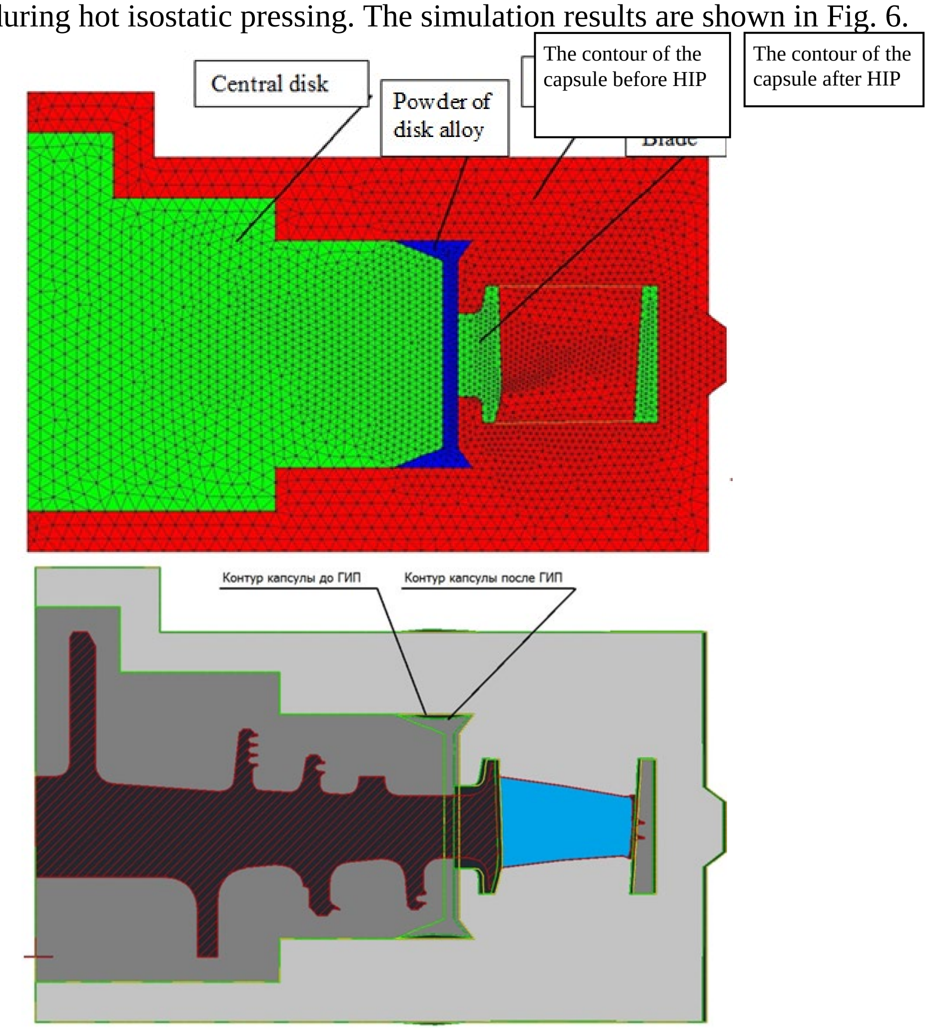
Figure 5 shows the individual elements of the capsule as well as snap-in assembly sequence of the capsule.

The mathematical modeling of HIP process is of particular interest, as the ultimate shape of the final product depends on the geometry of the capsules.

Acceptable mathematical model of HIP process should meet the following requirements.

1. It gives a dimensionally close first approximation;
2. It properly takes into account the influence of process parameters and rheological properties of the materials;
3. It allows making changes in the model parameters basing on the results of the experiment, and, if necessary, entering additional parameters.

The work was produced by the FEM Modeling of deformation of the capsule with powder, inserts and blades during hot isostatic pressing. The simulation results are shown in Fig. 6.



a)the scheme of assembly b) The contour of the capsule before (yellow) and after (green color) HIP

Fig. 6 Simulation results for the shrinkage of the HIP tooling

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The deformation of the capsule assembly during the process of hot isostatic pressing using FEA is calculated to determine the initial position of the blades with shrouds, to enable the mounting preload after the HIP and heat treatment. For the developed structure of the capsule assembly, the value of the initial gap between the central disk and the annular assembly of the blades and inserts was determined to be 5 mm. This gap is necessary for reliable filling of the powder material and its sustainable compaction. The initial density of the powder in the annular gap after vibration filling was 65%.

Analysis of the calculation results showed that the shrinkage of the powder is stable and occurs mainly in the radial direction. The value of the interference fit between the blade shrouds can be controlled by adjusting the magnitude of the gap.

The technological process of manufacturing of blisks with shrouded blades of the cast superalloy and disc from powder alloy is the following:

- Casting of the blades.
- Manufacturing of capsules for the central part of the disk and HIP of the central disc to minimize shrinkage at the final shaping of blisk.
- Manufacture of capsule assembly to connect the disc part and blades and the inserts.
- The assembly in the capsule tooling with blades and the disc part.
- Conduct of the HIP.
- Heat treatment and removal of the capsule and inserts, machining.

Summary

As a result of this work the technological process of manufacturing BB with shrouded blades by hot isostatic pressing method has been suggested and developed.

The capsules for forming the central part of disk and for assembling disk and blades were developed.

FEM Modeling of capsule and powder deformation during hot isostatic pressing process was carried out.

The elements of the tooling and technological process were designed.

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