NUMERICAL ANALYSES OF THE FEEDER NUMBER INFLUENCE ON THE RESIDUAL STRESS IN A STEEL CASTING

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Abstract. In the present article, the residual stresses, formed during the cooling of a steel sand casting, are achieved by computer simulation. The casting is a real industrial product - an elevator brake wheel made of low carbon steel. Calculations have been made for four different types of casting feedings - using one, two, three, and four main feeders. The distribution of the three principle stresses and the equivalent stresses in the one main feeder version have been shown. The maximum residual stress zones have been defined and the stress values in them have been specified. The formation of the stresses in these zones has been explained as well as the origin of the corresponding stress state. For two of the high value residual stress zones the formation course of the stresses during the casting cooling process has been shown. A comparison has been made between the casting residual stresses in the four considered versions. It has been shown that the feeders influence the casting residual stresses only in the zones near their necks. It has been established that the most appropriate would be to use just one main feeder.

Keywords: feeder, finite element method, residual stress, sand casting, steel

1. Introduction

The residual stress results from the uneven cooling of the castings [1]. When of high value these stress causes distortions and could lead to rupture during the production process. Even if there are no visible defects in the casting, the residual stresses are added to the operational ones and deteriorate the finished product strength characteristics. That is why they are highly undesirable and additional treatment is necessary to be applied, but this increases the production cost [2, 3]. Having good knowledge of the residual stress distribution is indispensable to the diminishing of the production cost and the scrap. This allows taking appropriate measures for their reduction as early as during the casting technology design process.

The type, form, number and disposition of the feeders are among the factors influencing the temporary temperature stresses and the residual stresses. The main reasons for this are:

- for the bare feeders: the big volume of the feeder; the fast heating of the form around the feeder after pouring the molten metal; the great heat-exchange between the feeder and the rest of the casting; the slowing-down of the casting cooling near the feeder;
- for the exothermic feeders: the small area of the feeder neck's cross-section, which appears to be the stress concentrator; the very slow cooling of the feeder, due to which there are considerable temperature gradients around its neck for a long time.

2. Problem description

The present research focuses on a product, which is being produced - an elevator brake wheel, shown on figure 1. It is casted from low carbon steel using the method of sand casting. The gross weight of the casting is about 120 kg. The gating system has not been modelled in the present research with the purpose of simplifying the calculations.

Figure 1. An elevator brake wheel

In order to obtain a defect-free casting, two types of feeders should be used - main and secondary ones (figures 2 and 3). The secondary feeders are six – one for each spoke. Their volume and place have been defined after solving an optimization problem and for the present research they remain unchanged.

The number of the main feeders can vary from 1 to 4 (figure 2). For each of these four versions an optimization problem has been solved with a standard dimensions exothermic FOSECO sleeve [4].

The minimum feeder volume allowing obtainment of a defect-free casting has been determined.

Figure 2. Casting versions with different number of main feeders

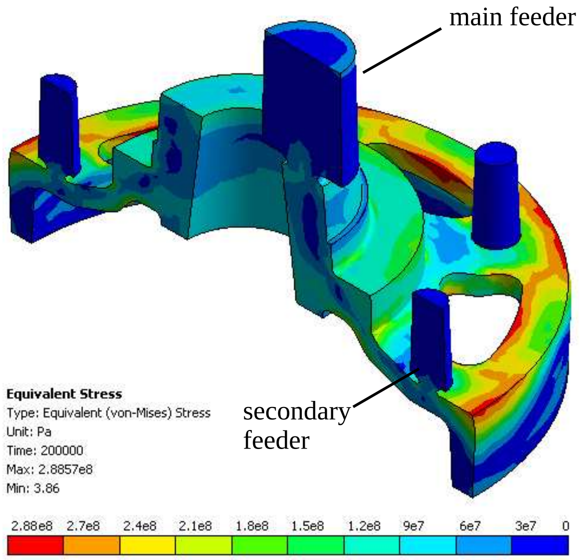

Figure 3. Equivalent residual stress in a casting with one main feeder

As seen from the figure, with the increase of the feeders number their individual volume decreases, but their volume as a whole is increased. The total feeder volume in the four versions corresponds respectively to 15.281; 15.879; 16.476; 16.411 dm^3. The most metal-saving version is that with one feeder. It is also the simplest and the cheapest one - as regards the consumables, the moulding and the machining. Its drawback, however, is the resulting asymmetry in the temperature field during the casting cooling, which is avoided in the other three versions. That's why before recommending the one main feeder version to the production, the influence of the feeder number and their place on the residual stresses distribution and magnitude should be carefully examined. The residual stresses are calculated with ANSYS – a universal software product for engineering analyses using the finite element method. The computer model used is described in [5].

3. Stress in a casting with one main feeder

The equivalent von Mises stresses (σ_{eq}), resulting in the casting after its cooling from molten metal temperature (1580°C) to room temperature, are shown on figure 3. A good knowledge of the cooling progress is indispensable for the understanding of the stress distribution.

After pouring the metal the bottom part of the wheel periphery is cooled most rapidly. The spokes and the upper part of the periphery are cooled with a certain delay. The slowest to cool is the massive central part and the feeder above it. First the periphery is compressed without any resistance from the hot and plastic central part. Then the periphery, having lower temperature and greater stiffness, counteracts the shrinking of the centre. The central part, through the spokes, pulls in the periphery, thus creating a tensile stress in the spokes and a compressive stress in the upper part of the periphery. Under high temperatures these temporary temperature stresses can easily exceed the metal elasticity limit. After cooling the resulting uneven plastic deformation causes the residual stresses, shown on figures 3 and 4.

The distribution of the maximum principle stress σ_1, the middle principle stress σ_2 and the minimum principle stress σ_3 is shown respectively on figure 4, A, B and C. It can be seen that in the casting there are three zones with high stress values – the upper part of the periphery (σ_3 = 285 MPa), the edges at the spoke apertures (σ_1 = 295 MPa and σ_2 = 20 MPa) and the transition from the spokes to the hub (σ_1 = 300 MPa and σ_3 = 95 MPa).

The residual stress formation in time in two of the high stress value zones is shown on figure 5. The simulation spans over an interval of 200,000 seconds. For this time the casting is cooled to room temperature. As seen from figure 5A, σ_1 and σ_2 in the periphery control point Probe 1, are practically equal to zero. We have there a one-dimensional stress state (pure compression). In the transition zone from the spokes to the hub (control point Probe 2, figure 5B) the stress state is three-dimensional, all three principle stresses being positive. The greatest value belongs to σ_1, which is greater than σ_{eq}.

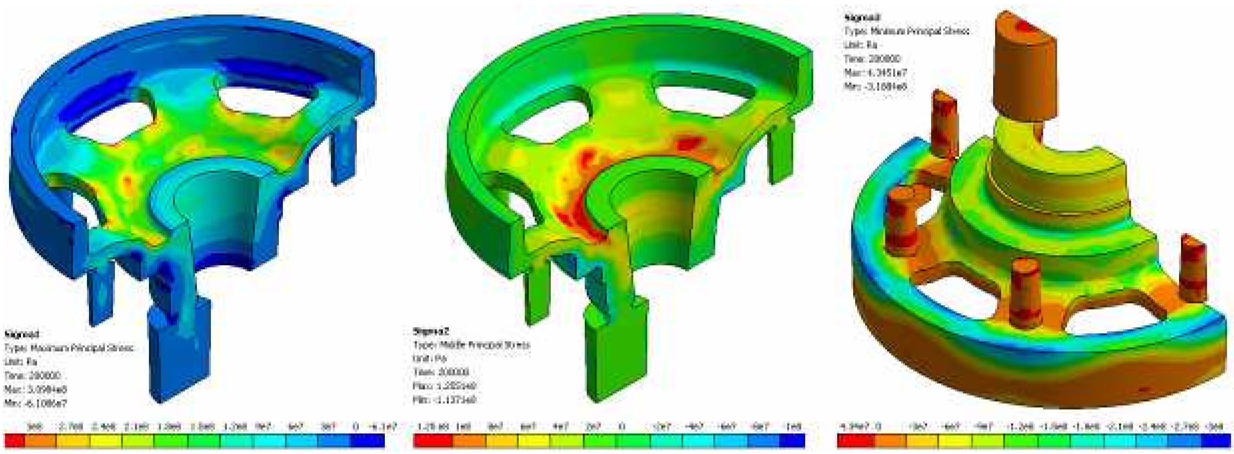

Figure 4. Principle residual stresses in a version with one main feeder

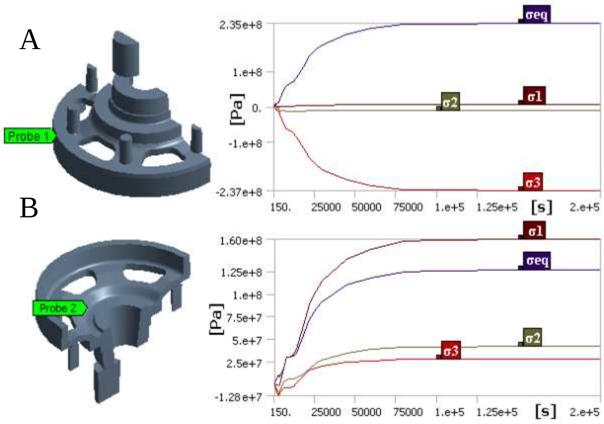

Figure 5. Residual stress formation
in control points Probe 1 and Probe 2

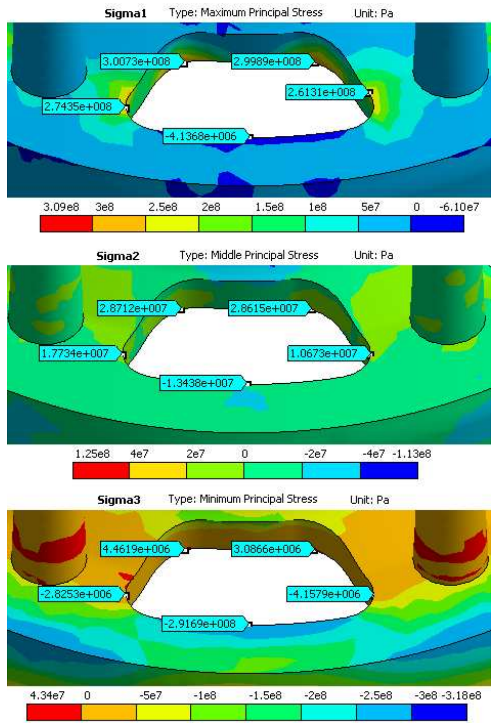

Figure 6. Principle stresses along the edges
of the apertures

The stress distribution along the edges of the apertures between the spokes - the third high stress value zone, is shown on figure 6. It can be seen that there are on the whole five stress concentration points along the edges. The stress state there is near to the one-dimensional, in the curves being tensile and in the edge on the peripheral side - compressive.

As the equivalent von Mises stresses give a clear general idea of the casting stress state, they will be used as a main criterion for the subsequent analyses as well.

4. Comparing the residual stress in castings with different number of main feeders

The equivalent stresses formed in castings with different number of main feeders are shown on figure 7 (figure 7A – one, figure 7B – two, figure 7C – three, figure 7D – four). As in the different cases the casting has one or two planes of symmetry, on figure 7, A and C, is shown a half, and on figure 7, B and D, a quarter of a casting.

The following observations can be made on figure 7:

- In all four versions the stresses are distributed in a relatively similar way.
- The number and the location of the main feeders influence the stress in their vicinity. The most unfavorable combination is when using just one main feeder (figure 7A) – in this case the maximum value of the equivalent stress reaches 111.3 MPa, while in the other cases it is under 100 MPa. The stress distribution on the surface touching the feeders is similar in all four versions - their values are within 88-100 MPa along the edges and 45-60 MPa in the middle.

All over the rest of the casting the stresses practically do not depend on the number and location of the feeders. The difference in the

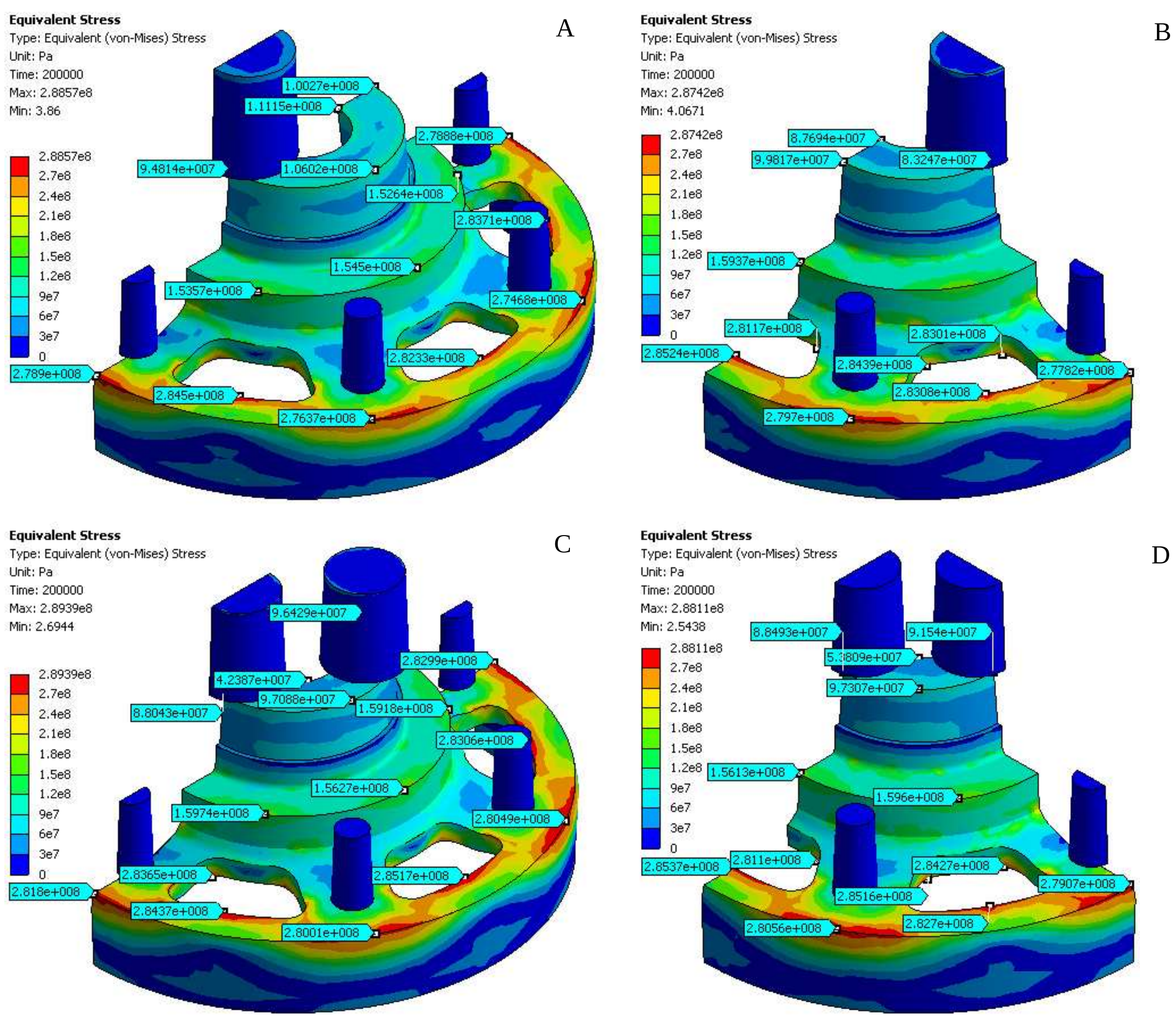

Figure 7. Equivalent residual stresses in versions with different main feeder number

residual stress values in the points of the same name in the different versions does not exceed 6%.

5. Inferences

1. The feeders have a substantial effect on the residual stress only in the volumes near their necks. In the considered versions the values of the stress in these volumes could vary with about 30%.
2. Further from the feeder neck their influence on the residual stress decreases reaching values of no consequence to the practice.
3. The residual stress values in the periphery of the wheel and in the spoke curves get near to the material yielding limit. These stresses are inadmissible from the operation load point of view, so that additional treatment will be necessary to reduce them.

6. Conclusion

The influence of the feeder number on the residual stress in the considered casting is relatively weak. This means, that the simplest design as regards the construction and technology, *i.e.* with one main feeder, should be preferred for the production.

References

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