MATERIAL ANALYSIS OF DEGRADED STEAM TURBINE ROTOR

This article deals with structural, fractographic and non-destructive analysis of a defective rotor made of 26NiCrMoV14-5 steel and assessment of possible technological failures resulting in the occurrence of cracking and subsequent defects. Metallographic analysis of the microstructure and evaluation of the steel metallurgical purity were executed, including analysis of inclusions present and ultrasonic testing. Attention was paid to fractographic analysis of fracture areas. Degradation possibilities were monitored in relation to technological failures. The aim was to elucidate the cause of the rotor defect hindering its operational use.

Keywords: Material analysis, production technology, metallurgical purity, hydrogen embrittlement, degradation.

1. Introduction

An important factor, indisputably affecting steel quality, is its metallurgical purity. Therefore, great attention should be paid to the presence of inclusions in steel. As known generally, formation and composition of inclusions mostly derives from chemical composition of steel and the way of its deoxidation and alloying [1 and 2]. Moreover, the type and character of inclusions significantly depends on oxygen content and treatment of inclusions during steel processing outside the furnace by means of calcium [3]. Contamination of steel by excessive rate of inclusions constitutes a significant cause leading to initiation of degradation processes, and thus to the product deterioration [4 and 5]. To achieve the required purity, it is also necessary to observe the correct production technology so that during both the production process and the steel treatment there are no defects occurring on the pertinent equipment, which would also result in impaired steel purity as well as quality. In extreme cases, the quality impairment may result even in the product degradation.

Examinations were performed on samples taken from the rotor forging of steel 26NiCrMoV14-5 for a steam power plant, made from an ingot of the weight of 70 tons. After primary processing in an electric arc furnace, the object molten steel for the turbine rotor was transported in a steelmaking ladle for processing outside the furnace in the ASEA SKF device. At the bottom of the ladle, there is an eccentrically installed porous block on which an argon inlet is installed. This provides for steel flushing, setting it in vertical motion. In this way, the melt in the ladle is properly homogenized, inclusions flown out and the melt degassed simultaneously [6]. To check the internal product quality, ultrasonic and magnetic tests are stipulated for the final product.

2. Material and experimental technique

The rotor was subjected to ultrasonic test which indicated inadmissible defects. For the actual material analysis, a plate of approximate width of 20 mm was cut out across

| C   | Mn | Si | P   | S  | Cr | Ni | Mo | V  | H* |
|-----|----|----|-----|----|----|----|----|----|----|
| Melting | 0.26 | 0.37 | 0.20 | 0.003 | 0.007 | 1.61 | 3.44 | 0.40 | 0.07 | 1.20 |
| Experimental plate | 0.32 | 0.39 | 0.23 | 0.004 | 0.001 | 1.66 | 3.43 | 0.42 | 0.008 | - |
| Specification | 0.24 | 0.35 | 0.15 | Max 0.007 | Max 0.02 | 1.55 - 1.70 | 3.40 | 0.40 | 0.07 | 0.80 |
| - | - | - | - | - | 1.45 | - | - | - | - |
| - | - | - | - | 0.45 | - | - | - | - | - |

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Table 1
individual dendrites were relatively fine; their size ranged about 1 mm and their arrangement was chaotic. To the depth of approx. 200 mm below the surface, the dendritic segregation was manifested less intensively than in the other parts of the forging cross section (Fig. 2). It was the areas of more evident segregations in which the above mentioned defects were detected. Moreover, a distinctive phenomenon in these areas was the spots of existence of stem segregates. The chaotically arranged dendrites and cross sections of stem segregations, not exceeding the size of 2 mm, are then presented in Fig. 3.

3. Results and discussion

During the ultrasonic test, inadmissibly large indications, bigger than 2 mm, were detected in the rotor examined around the forging axis on the head side of the ingot. The defective areas are encircled on the experimental plate (Fig. 1). In sum, 35 inadmissibly large indications of Dn 2.1 to 2.6 mm were found. Most of them were of Dn 2.1-2.2 mm, three of the indications had the dimension of Dn = 2.4 mm, one of them had the dimension of Dn = 2.6 mm. All indications were located at the depth of 427 – 558 mm below the surface of the rotor body. Almost the entire half of the rotor on the ground side of the ingot was without any inadmissible defects.

A Baumann print was executed on the rotor body cross section. Its appearance confirmed very low sulphur content in the steel (see Table 1). The occurrence of manganese sulphides was very low, particles were small, and sulphur did not concentrate at the macroscopic level very much either in the ingot head part or in the segregates where the segregation of elements is most evident.

Macrostructural analysis proved the presence of dendritic structure and dendritic segregation within the entire cross section of the forging machined, including its peripheral surface layers. The
The forging microstructure in the area where the defects occur consisted of tempered bainite; no visible structural changes were ascertained around the defects [8].

The following Fig. 9 presents the morphology of brittle transcrystalline cleavage. This was typical of substantial part of the fracture area. The fine cleavage facets are characteristic of the bainitic structure detected earlier by the metallographic analysis.

The fracture area of tensile tests featured defective zones which are typical as the so-called “fish eyes” (Fig. 10). The fish eye morphology is characteristic of defects resulting from hydrogen action [9]. This proposition is supported by the analysis of chemical composition. Apparently, the hydrogen content reached the value of 1.2 ppm, as opposed to the maximum admissible 0.8 ppm (see Table 1). Another
To the processing outside the furnace, as indicated above, the steel was transported in a ladle equipped in the bottom with an eccentrically installed porous block with argon inlet for steel flushing. Blasting of this inert gas sets the steel in vertical motion, which results in its proper homogenization in the ladle. Simultaneously, the inert gas bubbles cause flow-out of inclusions.

significant fact is the presence of intercrystalline failure on the fracture area in the vicinity of the fish eyes, as apparent in Fig. 11.

Figures 12 and 13 present inclusions in these defective zones of fracture areas. Figure 12 documents oxidic and oxysulphidic inclusions arranged in lines in the centre of the defective zone of the fracture area, Fig. 13 then shows these inclusions in detail.
4. Conclusions

Within the paper submitted, detailed material analysis was executed of the steam power plant rotor made of 26NiCrMoV14-5 steel. The aim was to assess the cause of its degradation. Particular attention was paid to the issue of metallurgical purity of the steel, which presents the decisive factor in the area of its quality.

On the basis of detailed material analysis, one can state that the secondary metallurgy equipment of ASEA SKF, which contains the inductive stirrer, is not efficient enough in the case of a defect in the porous block for melt flushing with inert gas. In the event of the above discussed defect, the melt is homogenized sufficiently, as apparent from, for instance, the chemical analysis; with regard to the volume of exothermic inclusions, however, it is not sufficient for production of steel with a high demand on internal quality. Likewise, the degree of degassing, despite the deep vacuum, does not achieve the required level. Owing to the increase in the hydrogen content together with the exothermic inclusions, the steel produced was deteriorated; in our case, even to the degradation of the rotor.

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