OPTIMIZATION OF THE MANUFACTURING PROCESS OF FORGING WITH FLANGE

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Abstract

The company of Vítkovice Heavy Machinery a. s. (VHM) has significant experiences with the production of various types of forgings, which are delivered to the whole world. However it´s appropriate to make an evaluation of process and find savings when introducing a new product into production or in case of rationalization of the product process itself. These savings may be due to reduction of production scrap (or necessary repairs on the product), reduce the time for production, possibly reducing the amount of material needed to manufacture etc.

In this paper we describe the optimization of production of the forging with a flange. We have focused on reducing the occurrence of defects in the flange region. These defects were recorded after quenching of the forging through ultrasonic examination in the area of the flange around the perimeter of the inner hole of the forging. Since the resolution of this problem should led to considerable improvement of the economic situation in the manufacture, it was decided to analyze the overall production process. This analysis consist of detail description of production, metallographic analysis in the affected area, magnetic and penetration testing, measurement of hardness and residual stress of the forging and also in mathematical simulation of quenching including the quenching with segregated inclusion. On the basis of this analysis were proposed measures, which should eliminate the occurrence of these defects (without increasing of production costs).

Keywords: Forging with Flange, ultrasonic indications, FEM simulation, SYSWELD, quenching

1. DESCRIPTION OF FORGINGS

Forging, which we deal with in this paper (**Fig. 1**), is forged from an ingot of low-alloy chrome molybdenum steel. The following table (**Table 1**) indicates the required chemical composition and chemical composition from the melting analysis (real chemical composition). These analyzes were performed for all heats and deviations from the standard composition is practically absent.

Fig. 1 Final shape of forging

Table 1 Chemical composition according to standard and real - for selected heats

	C	Mn	Si	P	S	Ni	Cr	Mo
Standard	0.38 - 0.45	0.5 - 0.9	max. 0.4	max. 0.035	max. 0.035	max. 0.7	0.9 - 1.2	0.15 - 0.3
Heat 1	0.410	0.830	0.130	0.0057	0.0018	0.606	1.060	0.260
Heat 2	0.407	0.807	0.144	0.0057	0.0013	0.635	1.034	0.259
Heat 3	0.413	0.830	0.152	0.0057	0.0010	0.627	1.068	0.280

The manufacturing process consists of upsetting, forging to the desired shape and of the last operation, in which the flange is upset in the matrix. After these operations forging is cooled and sent to the operation of drilling hole. This activity must be done before quenching. Furthermore, the forging is heated to a desired temperature, quenched in water and tempered. Then machining operations follows after quenching.

2. PROBLEM SOLVING

Using ultrasonic examination we demonstrated that the ultrasonic defects occur after quenching, therefore, we performed a balance sheet and suggested some possible causes of initialization of ultrasonic defects. Among these stress crack was when in the flange area stresses are maximum, then the presence of segregation that might initiate ultrasonic defects during quenching. To confirm or refute this hypothesis we performed metallographic test and mathematical simulation of quenching, including quenching of forging with proposed segregated inclusion. Due to the suspicion of the presence of residual stress after drilling hole [1] we performed tests on the surface of hole with the magnetic and penetration test, measurement of hardness and measurement of residual stresses.

2.1 Magnetic and penetration test

Due to refutation or confirmation the effect of machining on the formation of defects after quenching to the production process operations of penetration test [2] and the magnet examination [3] were added. These operations were performed on four pieces of forgings and results were without any indication. Based on these results, the influence of core drilling as a initiator of microcracks, which initiates larger cracks during quenching wasn´t confirmed.

2.2 Hardness measurement

Another assumption was that the coring process added tension into the material causes the initiation of cracks during subsequent quenching. This hypothesis was partially confirmed by preliminary measurements of hardness, which at a depth of about 0.5 mm confirmed the hardened layer, as shown in the following table (**Table 2**).

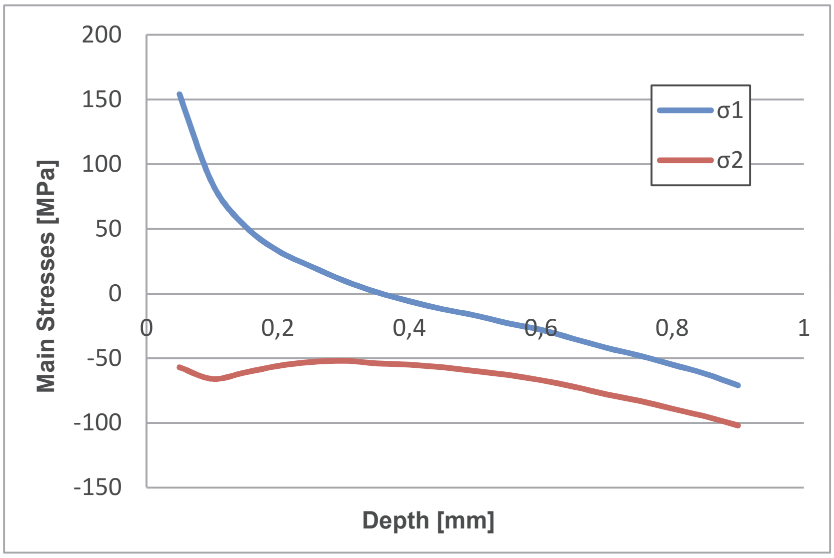
Table 2 HB hardness in various areas of the forging

No.	**In the flange area**			**From outside**			**Stem area**			**Pozn.**
240137	305	357	343	237	226	220	294	281	286	HB
	313	317	312				294	284	260	HB-2. On the surface
	292	268	278							HB-3. On the surface (-0.1mm)
	260	235	275							HB-4. On the surface (-0.2mm)
	251	256	247							HB-5. On the surface (-0.3mm)

Despite the fact that this hardened layer reaches a very small size and in this layer compressive stresses dominate [4], the elimination of this layer will be tested in the next chapter of this article.

2.3 Measurement of residual stresses

The hypothesis of local hardening after coring that we outlined in Section 2.2, was also confirmed by measurement of residual stresses [4]. However it must be noted that these tensions have especially compressive character that does not contribute to the formation of cracks. Progress of main stresses from the surface to the depth is shown in the following chart (**Fig. 2**) [5].



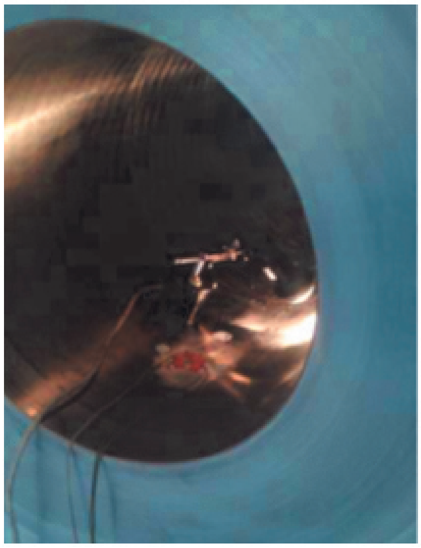


Fig. 2 Progress of main stresses from the surface to the depth

2.4 Metallographic analysis

Macrostructure examination was carried out on the taken samples. A more detailed study observed fine-grained structure with a slightly darker segregations in the interdendritic regions. Cracks were detected mainly equally oriented occurring at different levels evaluated slices.

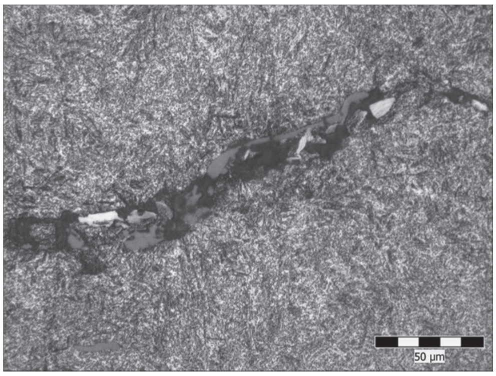


Fig. 3 Macro and microstructure

Because of the determination of the UZ defects, metallographic analysis was performed (**Fig. 3**). Results of the metallographic analysis from the defective area show that unsatisfactory ultrasonic indications correspond to cracks. These cracks were located in zones with strongly segregated structure observed in after tempering condition, which is associated with locally higher chemical heterogeneity of the ingot (flange of the forging is situated at the head of the ingot). Increased frequency of large unforged sulfide inclusions was in the areas of segregation which are occurring inside and close to cracks.

2.5 Simulation of quenching

Computer simulation of quenching [5] was used to clarify the formation of cracks including the mathematical simulation of the quenching with segregated inclusion. This inclusion was placed on the surface of the hole and slightly below the surface. From the results it is clear that segregated inclusion locally affects the stress and strain on the surface of the inner hole and causes an increase of tensile stress peaks during quenching. The highest tensile peaks are reached during quenching with inclusion on the surface. These peaks reached up to 3 times higher stresses then in the quenching of homogeneous one (**Fig. 4**).

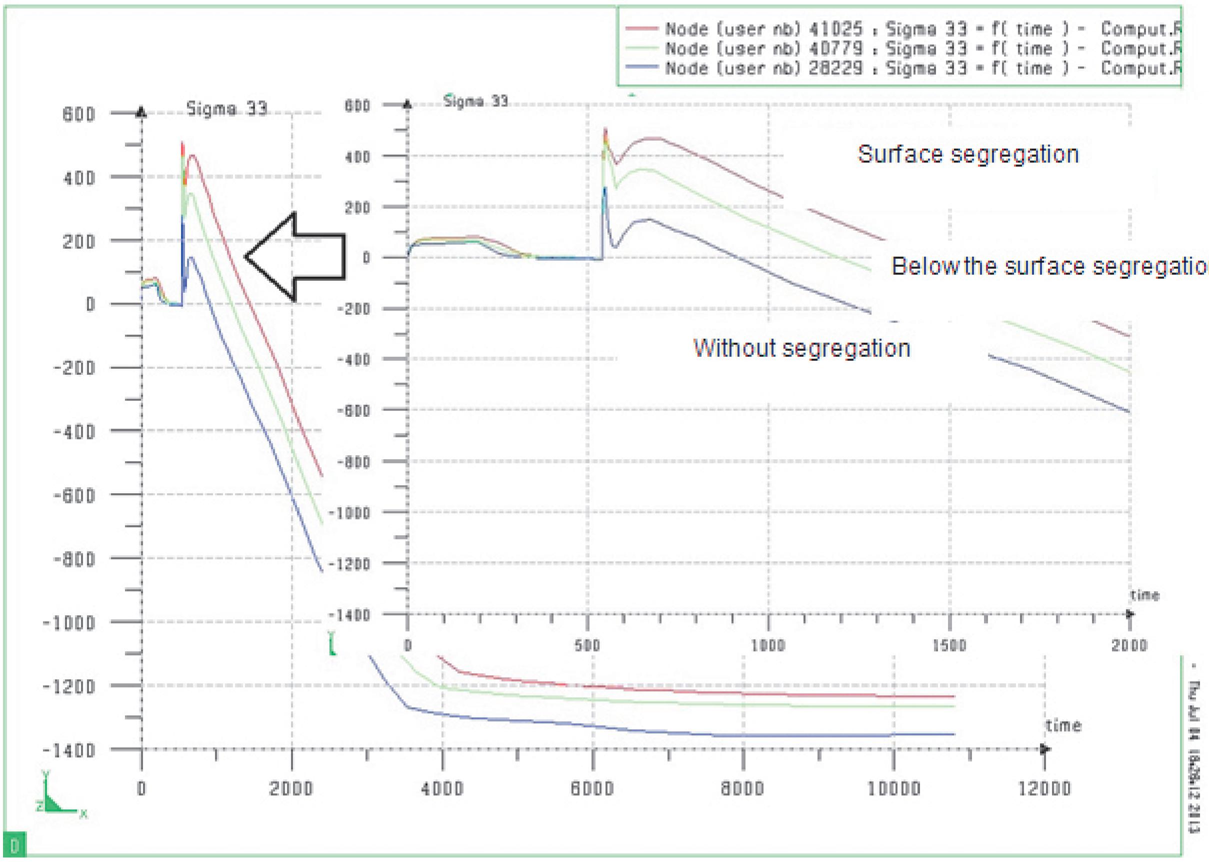


Fig. 4 Simulated stresses for material with segregation and without segregation

By placing segregations below the surface, the situation will improve. Tensile stresses are 2 times higher than in the quenching of homogeneous forging. Moreover, in this variant positively affects the material around the segregation (tensions have especially compressive character) (**Fig. 5**). In all cases, the tensile stresses will always cause the formation of tensile plastic deformation. In the hardened state in addition microstructure achieves considerable strength characteristics and the plastic properties are at minimum level. If the stress exceeds the cohesive strength of grain boundaries, then it will create a crack. Segregation represents local elevated concentration of alloying elements, especially carbon. In addition with increasing carbon content in addition reduce the cohesive strength of the material, which is another negative effect of segregation.

The simulations cannot clearly say at what place would crack occurs. Whether in the segregation, or in the surrounding material. From the above findings, however, it's more probable creation of crack in segregations.

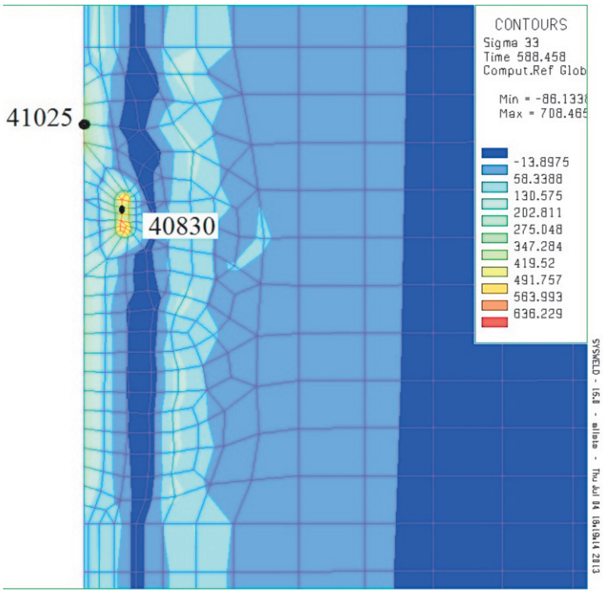


Fig. 5 Simulation - quenching with segregation

Finally, it should be added that the shape of segregation and its location in the item have a huge role in the distribution and in values of resulting stresses and strains.

3. REAL EXAMINATIONS PERFORMED

After evaluation analysis we proposed some experiments which we tested directly on forged pieces.

3.1 Machining after core drilling

This operation was designed to remove any hardened layer of surface after coring and thus to validate or refute the hypothesis that this layer is a cause of ultrasonic findings after quenching. Nine pieces of forgings with a drilled hole were selected. On these pieces a hardened layer was removed before quenching, i.e. about 2mm. During the evaluation, it was found that two of the nine tested pieces have also ultrasonic indications. The conclusion is that this measure is not effective.

3.2 Drilling holes of smaller diameter

Since the defects occur at the distance of several tens of millimeters from drilled surface it was suggested to drill a smaller diameter and subsequent machining to remove a hardened surface. This system should reduce the tension that develops in flange area. Possible cracks should get into an area that will be drilled after hardening. 6 pieces of forgings were used for this experiment. After evaluation the ultrasonic defects occurred in two pieces of them and therefore this measure is ineffective.

3.3 Turning of forging in the ingot

The considerate forging is manufactured from the ingot and the flange is situated in the head portion of the ingot. It is therefore possible that the flange area of the forging contains some impurities. It´s also possible that these inhomogeneities are given to the forging by upsetting of flange. As already demonstrated simulation (Section 2.5) these inhomogeneites may be a cause for the formation of cracks during quenching. For this reason, an attempt was made when forging was turned in the ingot. Currently, this test was carried out on five pieces and all of these were without ultrasonic findings. It seems that the measure is effective.

3.4 Using the larger format of ingot

From the same reason as in section 3.3 an attempt was made when the production of forgings used larger format of ingot. Even in this case results are still satisfactory. Also, this measure can be considered as effective.

CONCLUSION

This article aims to describe the case of optimizing of the production of forging with a flange. During evaluating the problem and finding solutions, we performed a complete analysis of production, the magnetic test, penetration test, hardness measurement, measurement of residual stresses in the material and, of course, metallographic analysis of the affected area of the forging.

Based on these results the simulation of quenching including the quenching with segregated inclusion was performed. This simulation confirmed that during quenching considerable stresses are in the area under the flange of forging. If some segregations are at this area stresses peaks achieve higher values and can become initiators of cracks - ultrasonic findings. These conclusions are confirmed by the current results of tests on real, physical forgings. Turning of forging in the ingot, as well as using larger sized ingot lead to a reduction of considerable amount of segregation in flange area. After heat treatment the pieces were without ultrasonic defects.

Other theoretically considered causes of defects - machining of surface after drilling and using of smaller diameter of inner hole have proved as ineffective.

REFERENCES

[1] MACURA, P. a kol.: Zbytková napětí jako parametr kvality výrobků. Hutnické listy č. 9, 2002, s. 22-28., roč. 57, č. 9, ISSN 0018 - 8069.

[2] EN 1371* Kontrola kapilární metodou, 2012, 32 str.

[3] EN 1369 Zkoušení magnetickou práškovou metodou, 2013, 28 str.

[4] MILTON C. Shaw: Metal Cutting Principles, Oxford University Press 2005, New York, 672 p., ISBN: 9780195142068

[5] ASTM E 837 - 08: Determining Residual Stresses by the Hole - Drilling Strain-Gage Method. Americká norma pro měření zbytkových napětí

[6] FOJTÍK, F.: Měření zbytkových napětí ve vybraných místech hřídele, VSB - TU Ostrava, 2013

[7] BÁRTA, J.; SZTEFEK, R.: Accelarated Cooling of Large Diameter C-Mn Steels in Water, Quenching or Normalizing. In 24th National Conference on Heat Treatment with International Participations. Jihlava, listopad 2012. ATZK- Jihlava. s. 100 - 108. ISBN: 978-80-904462-5-0.