ANALELE UNIVERSITĂȚII
"EFTIMIE MURGU" REȘIȚA
ANUL XX, NR. 1, 2013, ISSN 1453 - 7394

Cinca Ionel Lupinca, Constantin Marta, Relu Costel Ciubotariu, Rodica Radulea, Cornelia Ecaterina Cornean

Forming Tendency Distribution of Oxide Inclusions in Kaplan Blade Castings

The results of theoretical and practical studies realized on Kaplan rotor blades, cast from high steels alloyed with chromium and nickel represent the objective of this paper. The data presented refer to the distribution of alloy elements in the entire volume of the casting, resulted from the chemical composition analysis, determined on specimens taken from certain areas of the casting; the forming process and the distribution of oxide inclusions during the mould filling process and during the solidification process. In order to obtain results we have applied the AnyCasting simulation software. Microstructures of specimens from four different areas of the casting are also presented in this paper.

Keywords: *Kaplan blade, simulation, martensite*

1. Introduction

The Kaplan turbine, the invention of professor engineer Viktor Kaplan PhD (from Austria) (1913), is a hydraulic turbine with an axial rotation, with a rotor formed of 3-6 adjustable blades and it is used in hydroelectric power plants activated by a small water fall. In fact, the Kaplan turbine represents an improvement of the Francis turbine, the invention of engineer pale James B. Francis (USA) (1849).

There have been observed some problems in the Francis turbine referring to the *cavitation* formation (air bubbles are formed in the turbine water flow) which lead to pressure drops which lead to the decrease in the turbine efficiency. This deficiency has been removed in the Kaplan turbine, which uses adjustable blades. For an optimum performance the turbine needs a water race with a constant flow. The turbine works through the effect of supra-pressure, the efficiency reaching 80-95 %, this being optimum in the case of a water race with a large flow and with a small water fall.

In Romania, the design and construction of hydraulic turbines has known a great development starting with the second period of the 20^{th} century, in correlation with the industrial development in the domain, in Resita.

If in the beginning of hydraulic turbine fabrication in Romania, respectively in Resita, the rotor hubs and the Kaplan vanes have been cast from high steels alloyed with chromium and nickel which, in a solid state present a ferrite-austenite-martensite (XT08CuMoNiMnCr125Ti – internal norm at UCM Resita), today these components are cast from high steels alloyed with chromium and nickel (Table 1) (DIN 17007), with a structure that is mainly martensite (with low traces of residual austenite).

In this paper we will orient our attention towards the study of castings solidification – blades and of eventual conditions of forming and separation of non-metallic inclusions in their structure, through the application of the AnyCasting software.

It is already known that the Kaplan blades are very little corroded as a result of the cavitation phenomenon, fact proven by the long functioning of these types of aggregates on different Romanian rivers. This situation has been underlined by specimens from the Kaplan blades exploited for over 45 years and their structure has been studied to highlight small traces of corrosion through cavitation.

Table 1. Chemical composition of steel used in casting of the Kaplan turbine hub and blades [%]

Steel brand	C	Si	Mn	P	S	Cr	Ni	Mo
GX4CrNi3-4 (1.4313)	Max. 0,06	Max. 1,00	Max. 1,00	Max. 0,035	Max. 0,025	12,0-13,50	3,50-5,00	Max. 0,70
GX3CrNiMo13-4 (1.4314)	Max. 0,05	Max. 0,70	Max. 1,50	Max. 0,040	Max. 0,015	12,0-14,0	3,50-4,50	0,30-0,70

The Resita casting industry was based on steel production in electric arc furnaces with a capacity of 6,0-12,0 t, with a basic lining. The furnace metallic charge was represented, first of all by clean waste of alloy steel (in general alloyed with chromium and nickel) and the chemical composition was corrected by adding: FeCr85, metallic nickel, FeMo45. For the structure finishing, in a solid state and for the prevention of inter-granular corrosion we used the titan micro-alloying (0,12-15%) and eventually with niobium.

As we have mentioned these steel brands alloyed with chromium and nickel fulfil the conditions of a proper cavitation resistance, the cast blades having a high durability in exploitation (a few decades of functioning), without the need of re-conditioning and of reforming.

In Figure 1 we can observe the image of a Kaplan blade cracked and broken as a result of oxide inclusions left in the casting volume after the filling of the mould cavity with liquid steel.

Figure 1. The crack aspect of a Kaplan blade

In this paper we have proposed to highlight the metallographic structure of Kaplan blades cast from martensite steel (alloyed with chromium and nickel). We have also followed the filling of the mould cavity with metal liquid, the jet shape, the forming of non-metallic inclusions during the filling process and their distribution in the structure and in the casting volume, starting from the consideration that these non-metallic inclusions can influence in a non-favourable manner the compactness of the casting and its mechanical properties in exploitation.

The casting process has been realized in two temporary moulds, realized from a casting mixture based on natrium silicates, frozen by CO_2 blowing.

The study of casting mould filling "Kaplan rotor blade" and the solidification of cast steel, GX3CrNiMo13-4 (1.4414) has attained our attention towards a series of particularities regarding the chemical homogeneity of the casting, the existence of which was unknown by Romanian producers of castings of alloyed martensite steels, for the energetic industry (hydraulic turbines). Our study being of large proportions, we were also able to present the study of chromium, manganese and carbon distribution.

For the formulation of a plausible hypothesis regarding the production of a segregation phenomenon of the alloying elements, first of all we will refer to the theories emitted Nicolae Geru [1]. Thus, Nicolae Geru considers that this kind of steel, the metallographic structure of which is mainly martensite at room temperature, the existence of solid solutions based on carbides [$(Cr, Mn, Fe)_{23}C_6$] has been underlined, based on the pure chromium carbide ($Cr_{23}C_6$). Thus, in the casting realized from this alloyed steel brand, the production of chromium carbides in a pure form wouldn't be possible.

For the obtaining of a martensite structure in the casting, after the cooling of the steel cast, the proper cooling conditions must be insured, respectively a high cooling rate. Still, the study of temperature distribution in the liquid metal and in the casting has highlighted the existence of a thermal node (Fig. 2) in the area mentioned, which presents anomalies regarding the segregation of alloying elements.

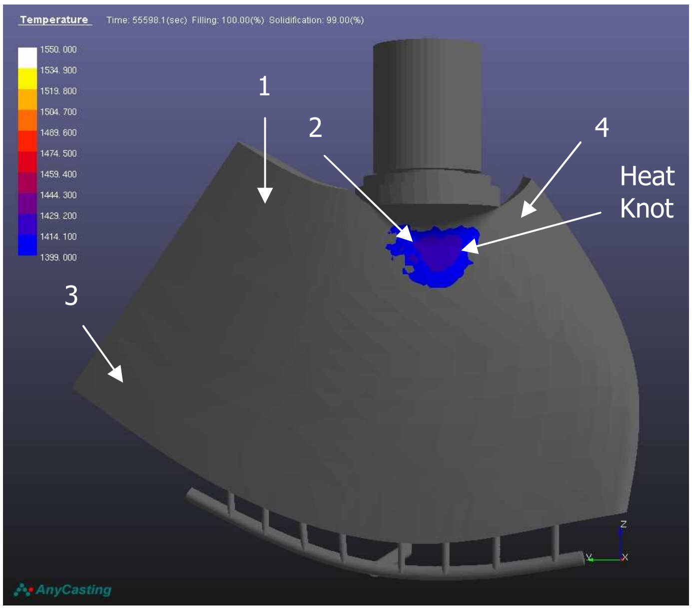


Figure 2. The positioning of the thermal node in the casting and in the areas of the specimens

It is also known the fact that the alloying elements situated in Mendeleev table, on the left side of iron (Cr, Mn), partially form carbides and are partially dissolved by ferrite [1].

According to the references information and to the researches realized by authors of this paper we may conclude that these chemical anomalies, observed with the help of the simulation software, during the casting process of the "Kaplan rotor blade" from alloyed steel, which should be characterized by a martensite matrix, in a solidified state, on the basis of industrial conditions (materials, cast mould, casting technology) may be a result, first of all, of the existence of the thermal node in the area highlighted, situation which allows the separation of residual austenite (of course, in a very small quantity) in this section (area) of the casting. Excepting this area, in the volume of the casting we can't observe any premises of separation of residual austenite during the solidification of alloyed steel and during the cooling of the casting.

2. Study of the metallographic structure in a solid state

The study of metallographic structure was axed on four specimens from a blade removed from exploitation after a functioning period of 45 years. In Figure 2 we have presented the areas from where the specimens were removed.

The chemical compositions determined for each specimen are presented in Table 2 highlighting the segregation phenomena of chemical elements during the solidification process of cast steel and during the casting cooling process.

Table 2. Chemical composition of specimens of the casting [%]

No. specimen	C	Si	Mn	P	S	Cu	Ni	Cr	Mo
1	0,06	0,34	0,40	0,02	0,010	0,14	3,8	12,7	0,35
2	0,07	0,41	0,56	0,027	0,014	0,16	5,17	11,15	0,35
3	0,055	0,62	0,65	0,021	0,012	0,25	3,62	12,95	0,36
4	0,06	0,43	0,42	0,015	0,009	0,07	3,81	12,5	0,32

In the figure 3 we present microstructures of four samples extracted from points indicated in figure 2.

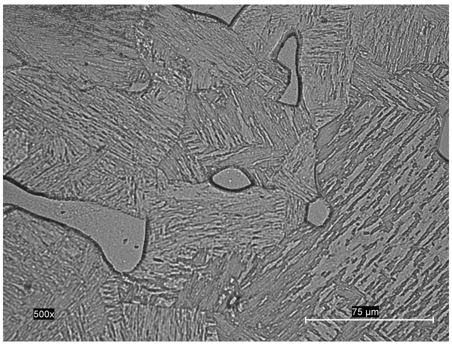
The analysis of chemical elements distribution on the specimens studies, respectively on the volume of the casting reveals significant variations of concentrations (especially of alloying elements concentrations, nickel and chromium).

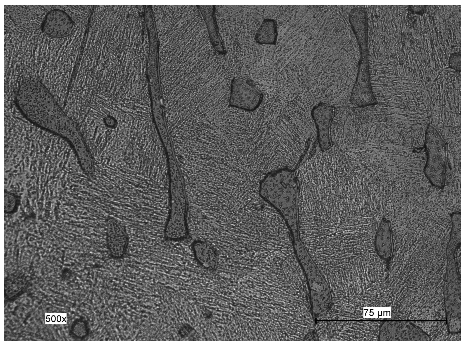
We can observe a decrease of the chromium content in the area where the casting has the greatest consistency, respectively the area of jointing between the blade shaft and a growth of the chromium content towards the area in which the casting wall is finer and which is the first to solidify (the most distant area from the charger)

On the other side, the nickel distribution in the casting volume is presented backwards than in the case of chromium.

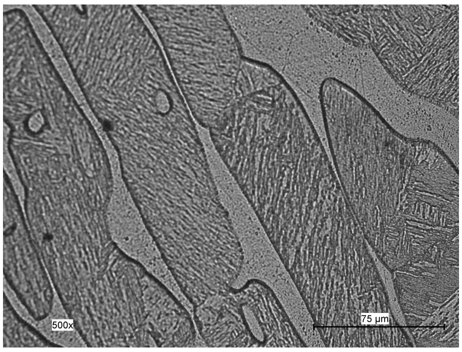
The analysis of the four specimen structures from the Kaplan blade casting doesn't show significant differences. In general, the metallic matrix of the casting is mainly martensite with a content of maximum 5 % of residual austenite.

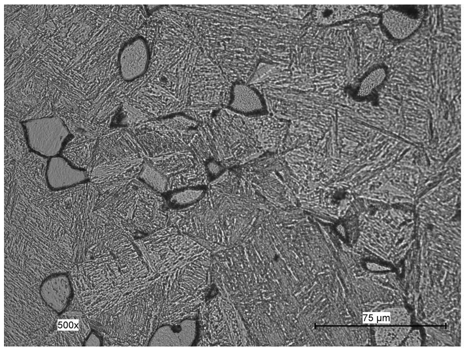
The forming possibility of oxide inclusions in the casting is highlighted by the simulation software which shows that these inclusions may be formed at the liquid-air matrix interface, during the filling with liquid steel. The so called film of oxide inclusions is realized in the following manner: it moves towards the superior part of the casting, respectively towards the feeder. In these conditions, reduced quantities of oxide inclusions may remain embedded in the upper-left corner of the casting, respectively of the entrance angle.





a. b.





c. d.

Figure 3. Microstructures (500X)

Thus, oxide inclusions are pushed towards the extremities of the casting, part of the casting that are first to solidify or they may remain embedded in the casting matrix (Fig. 4÷6).

4. Comments

Regarding the chemical composition of the four specimens studied, we can observe small differences of concentrations of chemical elements on the casting sections, fact which can lead us to the idea that during the cooling process and the solidification process of the steel casting – the Kaplan blade, chemical segregations are produced. The study of chemical elements segregations and especially of alloying elements will present the subject of a different scientific paper.

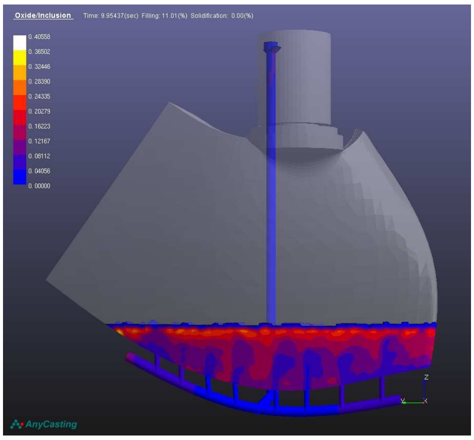


Figure 4. Forming and distribution of oxide inclusions – filling: approximately 11%

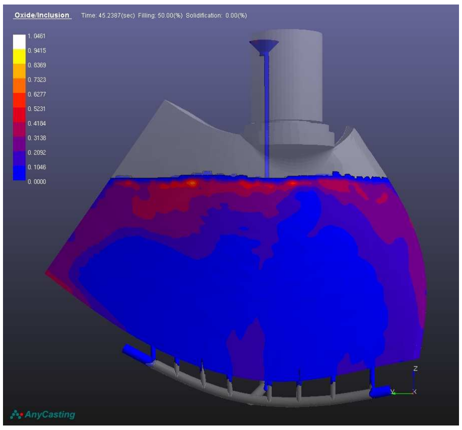


Figure 5. Forming and distribution of oxide inclusions – filling: approximately 50%

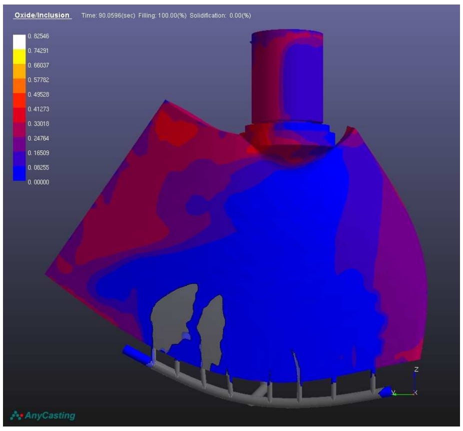


Figure 6. Forming and distribution of oxide inclusions – filling 100%

In general, the metallographic structure determined on the four specimens is mainly martensite. Small quantities of residual austenite are observed (maximum of 5%).

Oxide inclusions may be formed in the casting from the filling phase of the mould cavity at the liquid-air steel interface of the mould cavity. This phenomenon can be observed with the help of the simulation software.

The study of the cracking and breaking of the Kaplan blade, underlines the fact that the forming of oxide inclusions during the filling of the mould, especially on the liquid surface mass, may lead to the production of important casting defects of the cast piece.

This is the reason why, such a casting (Figure 1) could brake due to fluctuations during the filling process of the mould cavity with liquid metal, respectively the impossibility to maintain the casting network completely full. Thus, unobserved fluctuations during the filling of the mould sand expressed in the quality of the solidified casting surface, may lead to the forming of so called "interruptions" of tightness, and which in the future may lead to such a result.

References

[1] Geru, N., *Metalurgie fizică*, Didactic and Pedagogic Publishing House, Bucharest, 1981

[2] Flender E., Sturm, J., *Thirty years of casting process simulation, International Journal of Metalcasting*, American Foundry Society, Inc., Vol.4, Issue 2, 2010

[3] Cihal, V., Turek, M., Kandlecova, M., *The effect of titanium on passive stability of austenitic stainless steels,* Acta Metalurgica Slovaca Conference, 2010

[4] A. Kanni Raj, *On High-Temperature Materials: A Case on Creep and Oxidation of a Fully Austenitic Heat-Resistant Superalloy Stainless Steel Sheet*, Vol. 2013, Journal of Materials, www.hindavi.com/journals

[5] Jandova, D., Kasl J., Misek M., *Structure and mechanical propertie of cast steel microalloyed with titanium and vanadium,* Acta Metalurgica Slovaca Conference, 2010

[6] Ştefănescu D.M., *Science and Engineering of casting Solidification*, 2002, Kluver Academic/Plenum Publisher 233 Spring Street, New York, USA

[7] ***** AnyCasting, DataBase, Advanced Casting Simulation Software, Version 3.10, 2009

Addresses:

- Lect. Dr. Eng. Cinca Ionel Lupinca, "Eftimie Murgu" University of Reşiţa, Piaţa Traian Vuia, nr. 1-4, 320085, Reşiţa, c.lupinca@uem.ro
- Assoc. Prof. Dr. Eng. Constantin Marta, "Eftimie Murgu" University of Reşiţa, Piaţa Traian Vuia, nr. 1-4, 320085, Reşiţa, c.marta@uem.ro
- Assist. Dr. Eng. Relu Costel Ciubotariu, "Eftimie Murgu" University of Reşiţa, Piaţa Traian Vuia, nr. 1-4, 320085, Reşiţa, r.ciubotariu@uem.ro
- Assist Eng. Rodica Radulea, "Eftimie Murgu" University of Reşiţa, Piaţa Traian Vuia, nr. 1-4, 320085, Reşiţa, r.radulea@uem.ro
- B.D. Cornelia Ecaterina Cornean, "Eftimie Murgu" University of Reşiţa, Piaţa Traian Vuia, nr. 1-4, 320085, Reşiţa, lupinca_nelly@yahoo.com