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MATERIALS FOR MAKING CRANKSHAFTS AND THEIR FORGING DEGREE

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Abstract: This paper analyzes the conditions of elaborating the steels used for manufacturing large crankshafts. It states that the technical conditions required by the customer and the reception conditions of the manufacturer company are crucial for these crankshafts manufacturing and acceptance. Among these ones, global priority must be given to: American Bureau of Shipping, Bureau Veritas, Germanische Lloyd, Lloyd's Register of Shipping. The requirements for the forging degree and the material quality, such as: ease of obtaining the blank, good machinability, high fatigue strength and the possibility of obtaining a high hardness of the spindle surface are also clearly specified. Large crankshafts require crude ingots weighing between 5 and 60 tons, but increasing the ingots mass, their structural heterogeneity caused by the phenomenon of segregation increases and influences the constancy of the quality characteristics. It also states that the ingots structural heterogeneity can not be avoided completely, although it is influenced to some extent by controlling the melting, the temperature and the casting speed.
Keywords: crankshafts, specimens, forging degree, fatigue strength, base Siemens-Martin steel, crystal structure, structural heterogeneity

1. INTRODUCTION
The broadest domain of using the crankshafts is represented by the machine engines, particularly the internal combustion and steam engines.

The largest number of crankshafts are manufactured in the automotive, tractors industry, as well, in the aircraft engines and auto-ignition engines used in transport, mining and oil industry.

A smaller number of crankshafts are manufactured for steam engines: locomotives, marine machinery, machinery used in mining and oil industry. The largest crankshafts are used for high power self-ignition marine engines.

Heavy-duty crankshafts are also used in lever presses in forging workshops and other metallurgical equipment as well.

2. SCIENTIFICAL RESEARCH
The technical conditions required by the customer and the reception conditions of the execution company are crucial for the crankshafts execution and acceptance.

Among these, American Bureau of Shipping, Bureau Veritas, Germanische Lloyd, Lloyd's Register of Shipping should be mentioned with global priority.

The analyzis of these companiy demands leads to the conclusion that they perform the acceptances following the same principles having into view a higher safety in the large crankshafts operation [1, 2].

In case there are certain differences in the acceptance conditions, they confine only to various forms of samples, which again are based on national requirements.

For all these, the definitive tests that are generally performed are:

- Yield;
- Tensile strength;
- Tensile elongation;
- Breaking constriction;
- Bending behavior;
- Resilience.

The test sample are taken from the shaft end, from a section of the extreme bearings. For the larger crankshafts, the specimens are taken from both ends. When samples are taken from the both ends, there is the condition that the difference between the test results should not be less than 63 N/mm^2.

Regarding the steelmaking, there are no limiting prescriptions. The steel can be Siemens - Martin acid or base, or other category, but only with special approval if it takes part in the last category. Thus, the steel made in the electric furnace can be used too [3 ,4].

Reffering to the degree of forging, "Lloyd's Register of Shipping" prescribes that the forged section reported to the ingot section should be 1/5 to 2/3, which corresponds to a degree of forging of 5 to 1,5.

Generally crankshafts should be delivered in an annealed state, which means that they should undergo a normalization or quenching and cooling in air, but the users often require crankshafts in a tenacious and stress relieved state.

The users sometimes give indications in the order, on the heat treatment to which the crankshafts are to undergo.

The following requirements should be applied to the material used for manufacturing crankshafts such as: high fatigue strength, the possibility to obtain a high hardness of the spindle surface, good machinability and ease in obtaining the blank.

The crankshaft is performed by forging. The forged blank is obtain by forging in multiple passes and heating in closed molds, respecting the appropriate distribution of the material fiber and especially avoiding their twisting, which increases the fatigue strength of the shaft.

Since the shaft is generally oversized in the conditions of rigidity, the carbon unalloyed quality steels - type OLC 45, OLC 60 are utilized as manufacturing materials. The steels alloyed with Mn, Mo, V are used for highly-stressed crankshafts. The forged shafts undergo a heat treatment in order to obtain a hardness within 200 ... 250 HB. Spindles hardness is obtained by CIF quenching, the hardened layer depth is 3 ... 4 mm and the hardness is HRC = 52 ... 62, which provides increased abrasion resistance.

In most crankshaft, a tensile strength of 500-600 N/mm^2 is prescribed, while 600-700 N/mm^2 is provided at higher stresses. These conditions can be satisfied with the carbon steels OLC 35X and OLC 45X. In order to fulfill these conditions, the steel is often slightly alloyed with Cr up to 0,6%. If the stress is higher, for example if the tensile strength is required to be over 700 N / mm^2, it is recommended to use alloy steels.

The degree of utilization of the cast ingot in an as-forged part is 50-60%. Utilization degree of the machined crankshaft in comparison to the as-forged part is 28-35%. Thus, the total degree of material utilization is 15-20%.

Figure 1 schematically shows the example of forging a crankshaft with ten crankpins. The cast ingots mass is 40 tons, out of which the as-forged part is 24,5 tons, and the machined crankshaft is 8,3 tons. So the total utilization degree is 20,8%.

Figure 1 also shows that the shaft surface in comparison to the weight is very high, except for the end areas that are machined; the surfaces of the rough block appear at the crankshaft.

The cast ingots are in general directly used for large, freely forged crankshafts. They are more rarely used for pre- rolled forging blanks. However the ratios shown in Figure 1 are valid in both cases.

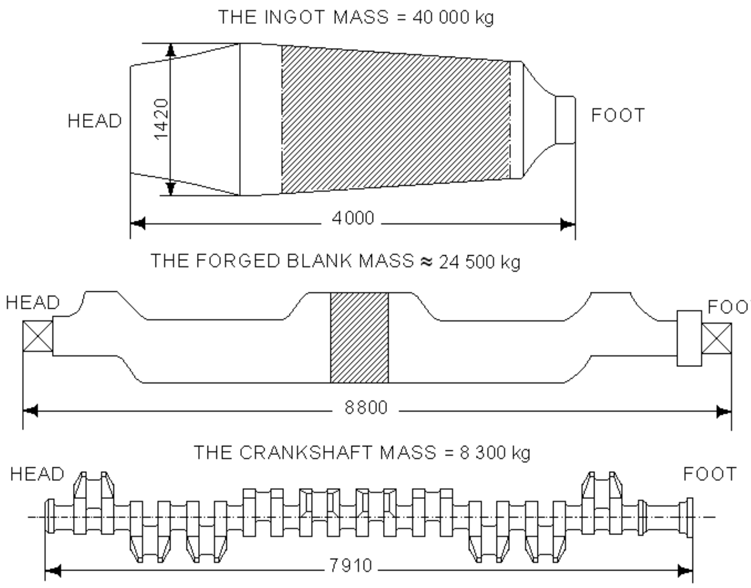

Figure 1. The utilization degree of the material at a crankshaft with ten crankpins

The treated crankshafts require raw ingots from 5 to 60 tons. The ingots destined for forging are cast from upsite and fitted with feeders at the top and at the bottom. If the steel used is a Siemens-Martin base, a charge is generally sufficient to the needed ingot. Several batches are usually required to fill the ingot for the steel in the base electric furnace [5, 6].

An ideal ingot is homogeneous both physically and chemically. It should have a fine equiaxed crystal structure and have no chemical segregation, non-metallic inclusions and voids. Unfortunately, the natural laws of the liquid metal solidification act against obtaining ideal conditions and the ingots contains well known inner defects such as cavitations, shrinkages, non-metallic segregation, columnar crystal structure and internal cracks. To these defects there are added internal defects and surface defects such as large or small cracks, shells [7].

A cast ingot can not be considered a homogeneous formation either in terms of crystals nor the distribution of components. This heterogeneity can not be completely avoided although it is influenced to some extent by controlling the melting temperature and the casting speed, etc.

The structural inhomogeneity caused by the phenomenon of segregation increases with the increase of the ingot size.

The amount of segregation contained by the ingot depends on several factors, among which we mention the chemical composition of the steel, their types (killed, semi-killed, with cap or non-killed) and their size.

A detailed explanation of the segregation, of crystal formation and of the ingot solidification speed is not the subject of this paper, but we recall that some steel elements tend to separate more easily than others. The sulphur is the most separated. The items listed below are separated in a lesser degree. They are given in the descending order of the separation degree: phosphorus, carbon, silicon and manganese.

The tendency of the elements to separate during solidification of the ingot increases with the elapsed period of solidification so the large ingots have higher segregation than the small ones [7, 8].

Figure 2 schematically shows the crystallization and segregation that occurs in an ingot. The marginal zone (1) cools more quickly and is characterized by ball shaped crystals. The next layer (2) consists of columnar crystals, followed by dendritic crystals (3). The area (4) located at the bottom of the ingot contains coarse crystallites in the shape of beads in a carbon-poor region.

Area (5) represents a significant part of the ingot showing an irregular solidification where shadow lines usually appear.This segregation region is characterized by a higher content of sulfur and phosphorus.

The shadow lines are formed at the solidification front where a precipitation of sulphide and oxide inclusions is formed by the remaining liquid by an imbalance and limited solubility [9, 10, 11].

If segregation is more pronounced, this phenomenon is better highlighted when machined.

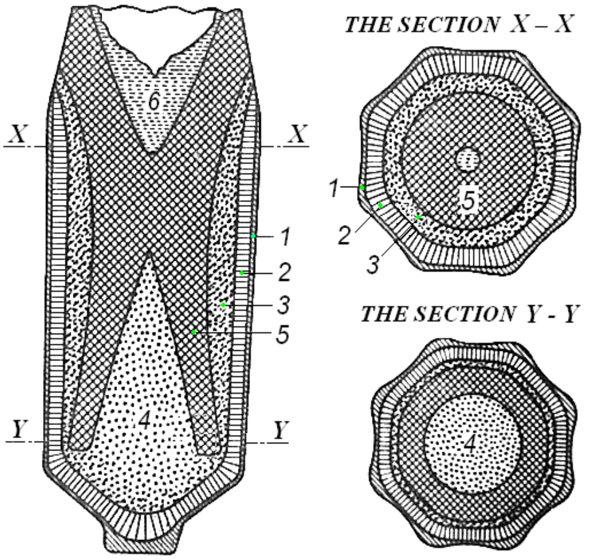

Figure 2. Schematic representation of crystallization and segregation in ingots: 1 - marginal zone, with fast cooling and fine globular crystal; 2 - columnar crystals; 3 - contact dendrites; 4 - coarse globular crystals (low-carbon region); 5 - segregation region with irregular solidification (areas where shadow lines may appear); 6 - uneven cooling area without segregation.

The segregation become better visible through Baumann samples or by treating with a solution of copper ammonium chloride. They appear in dark colour as dark lines in the longitudinal section and as points in the cross section.

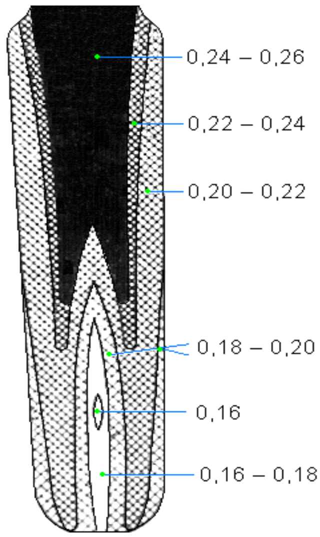

Figure 3. Carbon segregation in an ingot of 20 tons. OLC 22 with the analysis: C = 0,21%; Si = 0,17%; 0,66% Mn; P = 0,04%; S = 0,032%.

The powder collects itself in the areas of segregation at the magnetic defectoscopy. Different assessments of these segregation phenomena gave the strongest impulse during the investigation.

To this is added a strong carbon segregation that occurs by lowering the iron-rich crystals therefore poor in mixed crystals (carbon), a phenomenon that occurs at the foot of the ingot.

Figure 3 shows schematically the distribution of carbon in a 20 ton ingot that was cast from a 0,21% C steel.

The carbon content of the ingot ranges from 0,26% to 0,16% C, differences ranging up to 0,1%.

Figure 4 illustrates the distribution of carbon in an ingot of 23 tons, cast in OLC 35X steel. In the region that corresponds to the part to be forged, the carbon content varies between 0,38% (ingot head) and 0,32% (ingot foot).

This variation of the carbon content creates important diferernces for the value of the strength characteristics.

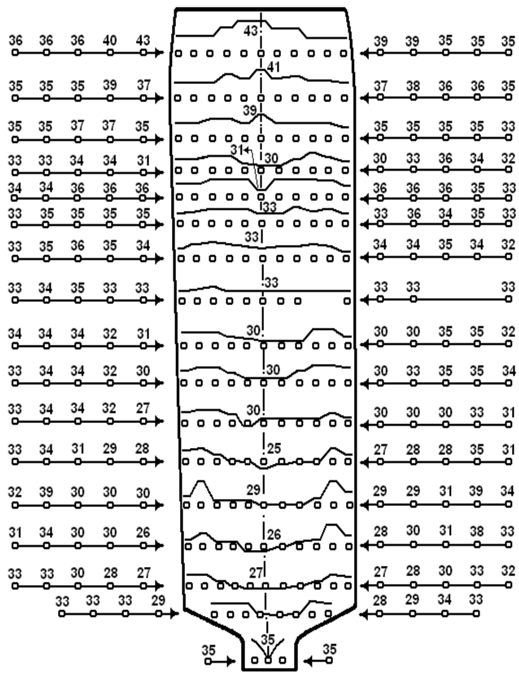

Figure 4. Carbon segregation in an ingot of 23 tons. OLC 35 X with the analysis: C = 0,35%; Si = 0,45%; Mn = 0,75%; P = 0,020%; S = 0,037%.

The acceptance condition is generally based on the material testing, which can be regarded as justified. These conditions come from the acceptance of the parts with high stress such as aircraft engines and other engines. The manufacturing conditions of the large engines, however, are quite different.

It is impossible to transpose the acceptance conditions of the large crankshafts individually manufactured to the small and high efficiency crankshafts which, in addition are manufactured from alloy steels. As for the large crankshafts, the conditions demanded by the exploiting domain must be valid.

3. CONCLUSIONS

The paper deals with the conditions that are necessary to manufacture steel crankshaft, the steel marks most appropriate depending on the operational requirements and the quality characteristics required by the national and foreign standards.

It analyzes the casting technology of the large forging ingots weighing up to 60 tons and their forging degree. It is noted that structural heterogeneity of the ingots can not be avoided completely, although it is influenced to some extent by controlling the melting temperature and casting speed. By increasing the ingot size, their structural heterogeneity also increases, influencing the constancy of quality characteristics.

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