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HALF-FINISHED TECHNOLOGY OF STEELS AND FATIGUE STRENGTH

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ABSTRACT

The paper presents the bending fatigue testing for four steel brands. The test showed that the fatigue strength is decreasing with the increasing of both ingot size and the rolled sheet thickness. The fatigue strength is varying following the ingot area and the orientation of cutting direction versus rolling direction.

KEYWORDS: fatigue strength, ingot cast steel, continuously cast steel, rolled sheet thickness.

1. General considerations

It is well known that the behaviour of elements in metal constructions (shapes, sheets) and certain machine elements (shafts, axes, crankshafts etc.) depends on the semi-finished products, casting and rolling technology, among others factors, [1]. As the result of initial solidification from the molten state, before any of the operations to forge or roll it into useful sizes and shapes have begun, inherent flaws are present in metal.

Primary pipe is shrinkage cavity that is formed at the top of an ingot during metal solidification, which can extend deep into the ingot. Blowholes are secondary pipe holes in metal that can occur when gas bubbles are trapped as the molten metal in an ingot mold solidifies. Many of these blowholes are clean on the interior and are welded sheet into sound metal during the first rolling or forging of the ingot. However, some do not weld and can appear as seams of laminations in finished products.

Segregation is a non-uniform distribution of various chemical constituents that can occur in a metal when an ingot or casting solidifies. Segregation can occur anywhere in the metal and is normally irregular in shape. However, there is a tendency for some constituents in the metal to concentrate in the liquid that solidifies last.

The conventionally ingot cast steels have strongly segregated non-uniform distributions of carbides oriented in the direction of rolling, [1]. The obtaining by ingot casting of pure metal, without segregations and blowholes has as consequence the removal of the center which forms primers of the breaking fissure, especially at variable strains. Practice shows that as the ingot dimensions increase, their crystallization coarsens and segregation accompany it.

In case of continuous casting the quite rapid solidification does not allow a good elimination of inclusions and blowhole through flotation. Continuous castings are the most efficient way to solidify large volumes of metal into simple shapes with consistent quality, [2].

The ensuring through rolling and thermal treatment of the semi-finished products uniform structure leads to splitting or welding workings, to the burns avoidance, zones with a higher hardness but which can be primers of breaking. In the case of rolling of steels obtained appears the impossibility of casting structure modification because the reduction rate by thermal plastic strain is too small. Though casting and rolling technology greatly influences fatigue strength, the existing literature contains generally qualitative information.

Statistical scatter [3] of fatigue strength is not only a very important factor for the high strength steels but also for the low strength steels containing various types of defects. Especially in ingot cast steels the fatigue strength is controlled by the non-metallic inclusions which become the fatigue fracture origin. In a volume of material subjected to the cyclic stress, the fatigue failure occurs at the largest defect that is present in the volume; fatigue fracture is the so-called weakest link phenomenon, [4, 5]. Thus the mechanical properties of steel are controlled to a large degree by the volume fraction, size, distribution, composition and morphology or inclusions and precipitates, which act as stress raisers, [6, 7, 8].

2. Tested materials and applied method

There have been studied four steel brands (Table 1) with: R_c = (353÷380) MPa; R_m = (520÷580) MPa.; A_5 = (22÷23)%.

Table 1

Brand		B_1	B_2	B_3	B_4
% C (ingot)	Max.	0.22	0.13	0.14	0.12
	Min.	0.12	0.09	0.13	0.10
% C (cont. casting)	Max.	0.21	0.10	0.15	0.16
	Min.	0.19	0.09	0.13	0.14

The samples have been alternately symmetrically bended by rotating them with a frequency of 1500 rot/min. Wöhler curves have been drawn based on the obtained results.

3. Experimental results

Figures 1, 2, 3, 4 contain the experimental results for steels B_1, B_2, B_3, B_4 respectively, [9, 10].

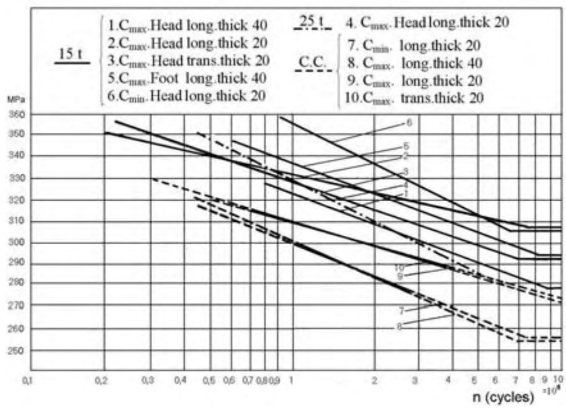

Fig.1. *Steel brand B_1*

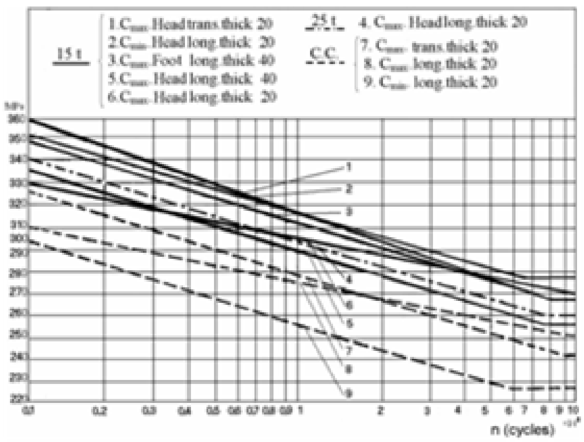

Fig.2. *Steel brand B_2*

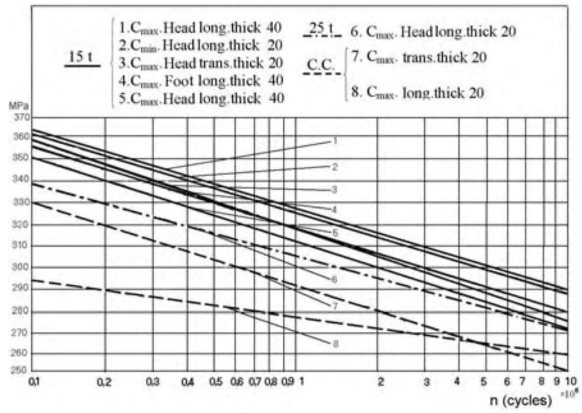

Fig.3 *Steel brand B_3*

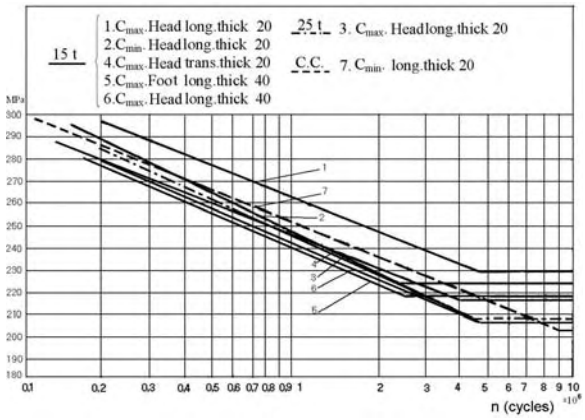

Fig.4. *Steel brand B_4*

The following abbreviations have been used:

C_{max}, C_{min} – maximum, respectively minimum percentage of carbon;

-head – samples from ingot's head;

-foot – samples from ingot's foot;

-long – samples cut on the rolling direction;

-trans – samples cut perpendicular on the rolling direction;

-15 t – ingot of 15 tons;

-25 t – ingot of 25 tons;

-thick.20 – samples made of 20 mm thickness sheets;

-thick.40 - samples made of 20 mm thickness sheets;

-c.c. - samples made of continuously casted sheets.

Tests prove that fatigue strength of samples made from ingots of 15 t is higher with around 10% than the fatigue strength of samples made from ingot of 25 t (figure 1, curves 2 and 4; figure 2, curves 6 and 4; figure 3 curves 1 and 9; figure 4 curves 1 and 9).

Samples of sheets from ingot's foot have a fatigue strength higher with around 5% than of samples drawn from ingot's head (figure 1, curves 5 and 1;

figure 2 curves 6 and 4; figure 3 curves 6 and 2; figure 4 curves 4 and 6).

Samples made of 20 mm sheets have a fatigue strength of about 10% higher than those of 40 mm (figure 1, curves 2 and 1; figure 2, curves 3 and 5; figure 3, curves 1 and 2; figure 4, curves 3 and 1).

Fatigue strength generally diminishes at samples transversally drawn in comparison with those longitudinally drawn (figure 1, curves 3 and 1; figure 2, curves 6 and 1; figure 3, curves 3 and 1; figure 4, curves 4 and 1). For samples drawn of sheets obtained from ingots the influence of carbon content on fatigue strength within the same steel brand is negligible (figure 1, curves 5 and 1; figure 2, curves 1 and 2; figure 3, curves 1 and 2; figure 4, curves 4 and 1). For samples drawn of continuously casted steel sheets the fatigue strength is not influenced by the rolling direction (figure 1, curves 9 ad 10; figure 3, curves 7 and 8; figure 4, curves 7 and 8).

The diminishing of continuously casted sheet thickness has as effect the increase of fatigue strength. Thus, the diminishing of sheet thickness from 40 to 20 mm leads to a fatigue strength increase around 5% (figure 1, curves 8 and 9; curves 9 and 8).

Unlike sheets obtained of ingot in case of continuously casting, within the same steel brand, the influence of carbon content on the fatigue strength is most obvious.

Thus, by increasing the carbon content the fatigue strength increases as well (figure 1, curves 9 and 7; figure 4, curves 8 and 9).

The fatigue limit of steel obtained by continuous casting is smaller than that of ingot cast steel (figure 1, curves 2 and 7; figure 2, curves 1 and 7; figure 3, curves 1 and 8; figure 4, curves 1 and 7).

The values of fatigue strength obtained for tested materials are presented in Table 2.

Table 2

Steel brand	Ingot type		σ_{-1} [MPa]			
			20 mm thick.		40 mm tick.	
			long.	trans.	long.	trans.
B_1	15 t	head	305 (305)	290	275	-
		foot	-	-	295	-
	25 t	head	280	-	-	-
		foot	-	-	-	
	cont. cast.		275 (255)	-	255	-
B_2	15 t	head	270 (280)	265	255	-
		foot	-	-	270	-
	25 t	head	260	-	-	-
		foot	-	-	-	-
	cont. cast.		250 (225)	240	-	-
B_3	15 t	head	290 (290)	275	270	-
		foot	-	-	-	-
	25 t	head	270	-	-	-
		foot	-	-	-	-
	cont. cast.		250	260	-	-
B_4	15 t	head	230 (205)	220	205	-
		foot	-	-	220	-
	25 t	head	205	-	-	-
		foot	-	-	-	-
	cont. cast.		(205)	-	-	-

Note: the values in the brackets are obtained for a minimum carbon percentage.

The analysis of fatigue tests on samples made by ingot steel brands (figures 5, 6, 7, 8) show a narrow scatter of experimental results.

Results obtained at testing the samples obtained by continuously casting technology shows a wider scatter of results (figure 9).

The two behaviour types in case of fatigue subjected samples can be considered as a result of a higher reduction ratio, due to rolling technology, in case of samples obtained from ingot comparing with those obtained by continuously casting method.

The same aspects can be praised in the results' scattering area analysis in fatigue life case, table 3.

The slopes of fatigue curves of steel brands (Eq.1) result from linear regression analysis.

$$k = \frac{\sigma_2 - \sigma_1}{\lg N_1 - \lg N_2} \quad (1)$$

Following the concept of normalized Wöhler curves [11] was analyzed the scatter band of experimental results (table 3).

The experimental results are included between a inferior and superior curves resulted from regression analysis.

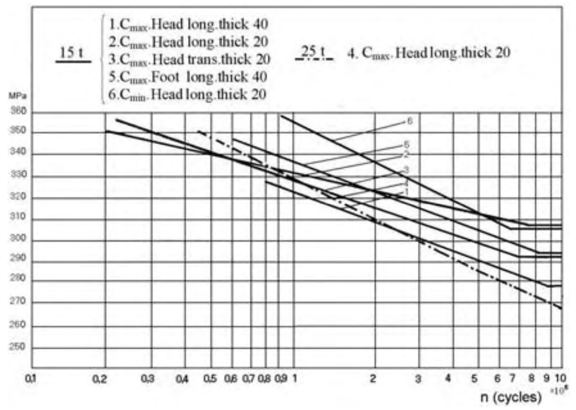

Fig.5. *Steel brand B_1 – ingot cast*

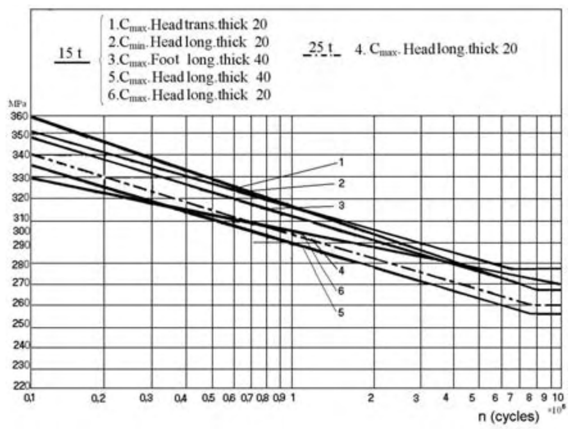

Fig.6. *Steel brand B_2 – ingot cast*

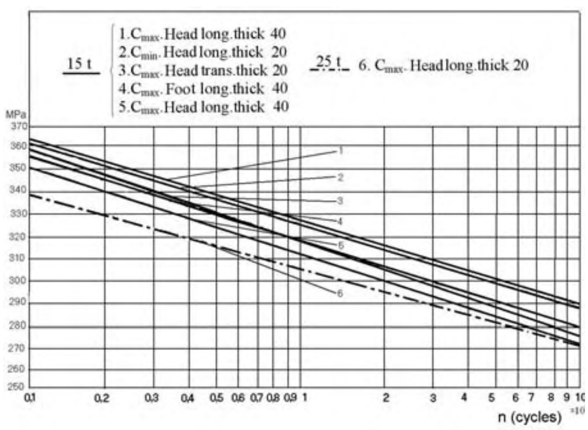

Fig.7. *Steel brand B3 – ingot cast*

Table 3

Steel brand	Slopes of fatigue curves **k**		
	inferior	superior	difference
B_1 – ingot cast	52,17	62,31	10,14
B_2 – ingot cast	43,7	50,72	7,02
B_3 – ingot cast	36,23	36,23	0
B_4 – ingot cast	46,15	48,83	2,68
cont. cast	36,23	50,79	14,56

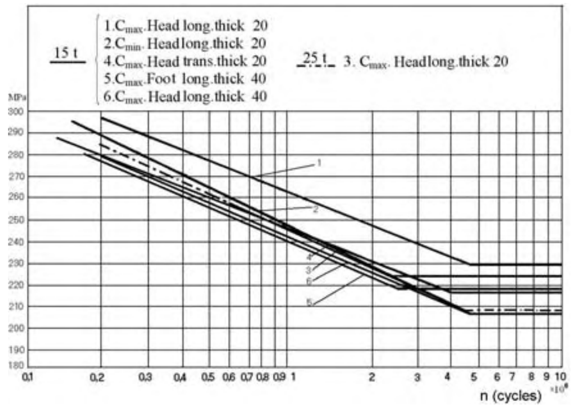

Fig.8. *Steel brand B4 – ingot cast*

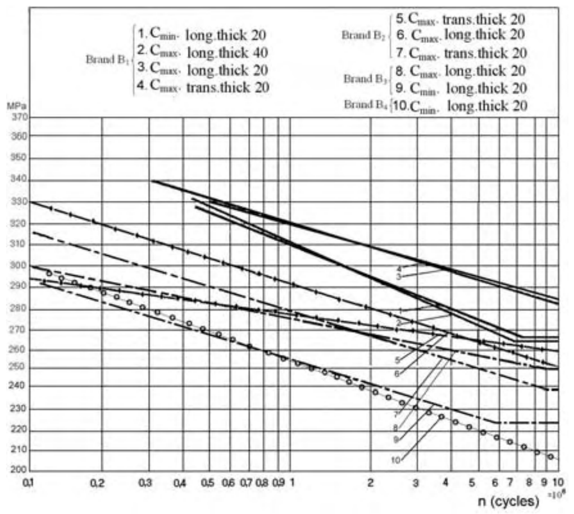

Fig.9. *Continuously casting steel*

4. Conclusions

The experimental tests worked on the four steel brands indicate that:

- Fatigue strength increases with the diminishing of both ingots dimensions and rolled sheets thickness, in case of either ingot cast steel and continuously cast steel. Rolled sheets of ingot’s foot have higher fatigue strength than those rolled from ingot’s head. Fatigue strength is higher for samples cut on longitudinal direction than those cut on transversal direction in case of ingot rolled sheets. This phenomenon is not manifest in the case of continuously steel rolled sheets.

- Fatigue strength increases with the increase of carbon content. Within the same steel brand, for the ingot rolled sheets the variation of carbon percentage is negligible. For the sheets rolled of continuously cast steel, the fatigue strength increases the carbon content
- The fatigue strength of continuously cast steel is about 15% smaller than that of ingot cast steel.
- Experimental results indicate a wider scattering area for fatigue resistance values obtained in continuously casting case samples, comparing to the ingot cast ones.

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