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Quantitative evaluation of the structure and properties of hot rolled products of continuous ingots made of low-carbon steels

J. Herian [a,*], R. Sułkowski [b]
[a] Department of Process Modelling and Medical Engineering,
Silesian University of Technology, ul. Krasińskiego 8, 40-019 Katowice, Poland
[b] LOI Poland, ul. Zagórska 79, 42-680 Tarnowskie Góry, Poland
* Corresponding author: E-mail address: jerzy.herian@polsl.pl

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Materials

ABSTRACT

Purpose: The paper presents influence of degree processing for parameters of the structure and properties of products after hot rolling of continuous ingots made of low carbon steels.
Design/methodology/approach: Ingots with cross sections of 105x105 mm and 135x135mm were rolled to wire rod and bars respectively, with applying the degree of processing λ = 6.5-115 and λ= 3-14. Tests of the microstructure parameters and their distributions were carried out on a SEM HITACHI S-4200, using the Met-Ilo computer application.
Findings: Parameters of the structure and properties of steel after hot rolling of a continuous ingot made of low-carbon steel and after air-cooling, significantly depend on the degree of processing. After the hot rolling process of the continuous ingots of steel of S355J2 grade within the range of the degree of processing λ =2.97-14.15, a structure of ferritic-pearlitic steel with heterogeneous distribution on the cross-section was revealed.
Practical implications: A good quality of products after hot rolling is obtain for minimal degree of processing, which will ensure obtaining an advantageous structure and properties.
Originality/value: The finding of the quantitative relations between the degree of processing, the structure and properties allows for predicting the minimal value of the degree of processing, which should guarantee obtaining the required structural features and consequently, product's functional properties.
Keywords: Metallic alloys; Plastic forming; Mechanical properties; Microstructure; Quantitative analysis

1. Introduction

Currently, when manufacturing long rolled products from structural steels (wire rod and bars), mill feedstock in the form of ingots coming from continuous casting is used. After heating, the continuous ingots are plastically deformed in consecutive passes, in a fixed sequence of roll passes. Their number results from the existing roll pass design for a given shape and size of a product.

Any discontinuities and voids in the material being deformed are gradually becoming closed and welded. Together with a decreasing temperature and increasing total strain, the microstructure changes [1-5]. The grain size is reduced and the grain shape undergoes homogenization [3,6-8].The outcome of rolling, depending on the degree of processing and with repeatable cooling conditions, are products of formed structure and properties [5,8,9,10].

The characteristic parameters, such as the size of ferrite grain or pearlite colonies, the grain shape coefficient, the relative surface fraction of grain boundaries, the volume fraction of phases and resistance (R_e, R_m) and plastic (A_5, Z) properties, depend not only on process parameters, but also on a factor called the degree of processing [1-3,10]. In the processes of plastic forming, this index is most often defined by the elongation factor ($\lambda = l_n/l_o$ or $\lambda = S_o/S_n$) or the real substitute strain.

The required properties of rolled products and their repeatability were obtained from conventional ingots when the value of the degree of processing amounted to several dozen. In case of continuous ingots, this value is much lower and amounts to 3-10 [7,9]. In some cases, for example when rolling pipes, the value is higher and equals 18 [9]. The constant strive to reduce the cross-section size of continuous ingots makes the degree of processing of an ingot until obtaining a final product significantly lower than in case of the technology of rolling products from conventional ingots. For these reasons, it is legitimate to define the minimal degree of processing, which will ensure obtaining an advantageous structure and properties in accordance with the expected requirements. Therefore, this subject is important not only from a cognitive, but also from a utilitarian point of view.

2. Structure of low-carbon steelsafter applying different degrees of processing

The evaluation of 105x105mm ingot's macrostructure of low-carbon steel with carbon content C=0,06% of C4D grade according to DIN-EN10016-2.T ests carried out for steel of C4D grade concerning the microstructure on the band cross-section after applying various degrees of processing revealed microstructure of a ferritic type (Fig. 1). The average surface area of a flat grain and grain shape coefficient was determined with use of Morpopercolor image analyser coupled with Neophot 32 light microscope and with use of Met-Ilo computer application. The degree of processing was determined on the base of calculated surface area of a cross-section of an ingot and band after and – this pass. In case of a lower degree of processing , λ=6.6, the surface area of grain is largely diversified (Fig. 1a). Apart from larger grains, fine grains occur in a smaller quantity. The large diversification of grain is showed by the distribution of their frequency of occurrence on the cross-section. The surface area of a flat grain decreases as the degree of processing of the ingot increases (Fig. 2) and in the range of λ = 30-115, it becomes stable at a level of 315 -330 μm^2 and is almost three times smaller than for λ=6.6.

The coefficient of grain shape (ξ) increases as the degree of processing increases (Fig. 3). It means that the grain shape becomes more equiaxial. The distribution of frequency of the grain shape coefficient occurrence changes from a normal distribution for λ =6.6 to exponential distribution for λ =115. This high degree of processing is accompanied with strong homogenization of the ferrite grain shape. Structural tests of the steel grade S355J2 (18G2A) after applying various degrees of processing for a square ingot, 135x135 mm, coming from continuous casting, revealed the occurrence of a ferritic-pearlitic structure of diverse morphology on the cross-section (Fig. 4). On the cross-section of the band, inhomogeneity of ferrite grains and pearlite colonies is to be found, in particular between the close-to-surface zone along the band's side and the zone close to the axis of symmetry (Fig. 4). Places where pictures of the structure were taken on the band's cross-section after a given degree of processing are marked).

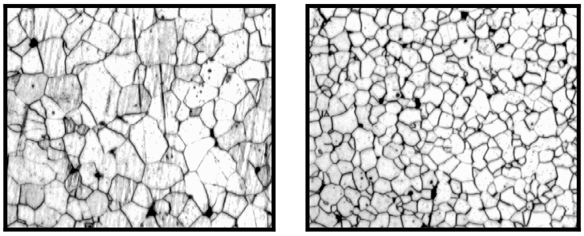

Fig. 1. Ferritic structure of steel after different degrees of processing : a - λ_{c6} = 6. 6; b - λ_{c17} = 115.5. Magnification 156 X

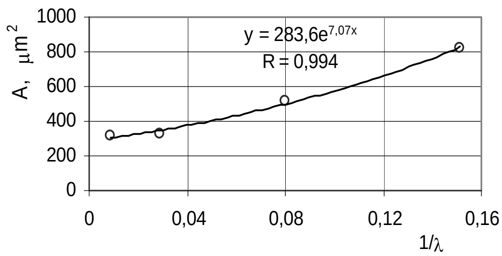

Fig. 2. Average area of flat grain, depending on the converse degree of processing

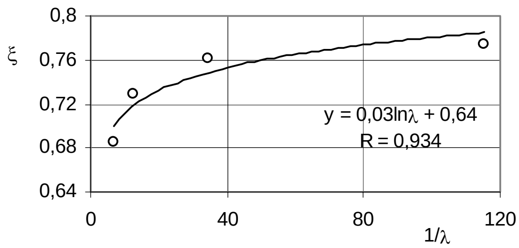

Fig. 3. Dependency of the grain shape coefficient on the degree of processing of a continuous ingot

The increase of the degree of processing of an ingot from 3 to 14.2 results in a reduction of the average surface area of the flat ferrite grain from the value of 330-360 μm^2 to 170-185 μm^2 (Fig. 5). For the same scope of processing, the pearlite colonies decrease too, from 260-330 μm^2 to 100-170 μm^2 (Fig. 6). Within the whole range of the degree of processing and for the same value for the analysed zones, the differences between the average values of the area of the flat ferrite grain and pearlite colonies are almost stable. In case of ferrite, this difference is about A_F = 37-25 and for pearlite colonies A_P = 74-56 μm^2 respectively for the degree of processing λ = 3-14.2.

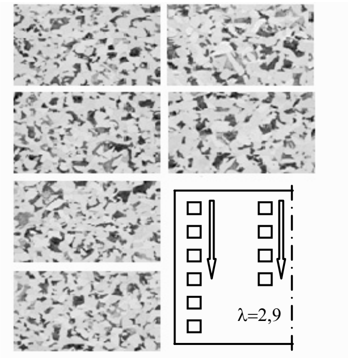

Fig. 4. The structure of ferritic-pearlitic steel after applying various degrees of processing in the process of rolling bars from a continuous ingot. Magnification 300x

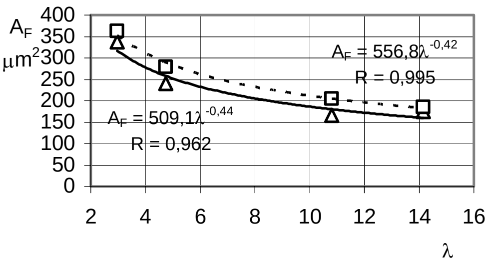

Fig. 5. Surface area of the flat ferrite grain, depending on the degree of processing: for the band zone along the side - solid line, for the band zone close to the axis of symmetry – dotted line

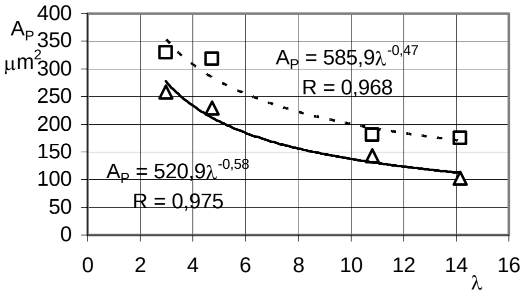

Fig. 6. Surface area of the flat pearlite colony, depending on the degree of processing: for the band zone along the side - solid line, for the band zone close to the axis of symmetry – dotted line

The determined distributions of fraction of the relative area of ferrite grains and pearlite colonies after applying different degrees of processing , for the assumed 10 classes, are of a normal type. For the degree of processing λ=3, the value of the average surface area of the ferrite grain was from 20 μm^2 to 4000 μm^2. Further increase of the degree of processing to λ = 14.2 resulted in size reduction of the ferrite grain surface area of to the range of 4.6-1800 μm^2.

Similarly, the average surface area of a pearlite colony decreases as the degree of processing increases. The nature of changes in distribution of the surface areas of pearlite colonies is similar to the changes in distribution of the ferrite grains areas. The surface fraction of grains with surface area of 65-6000 μm^2, corresponding to the degree of processing decreased significantly to 55-2000 μm^2 for the degree of processing λ=14.

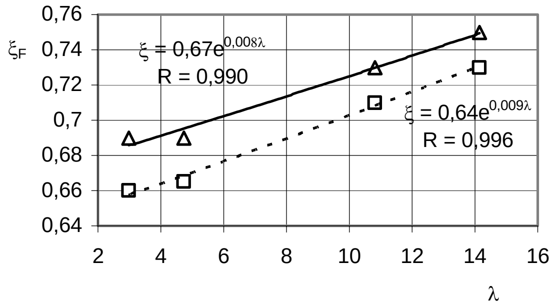

Fig. 7. Shape coefficient of the ferrite grains, depending on the degree of processing : for the band zone along the side - solid line, for the band zone close to the axis of symmetry – dotted line

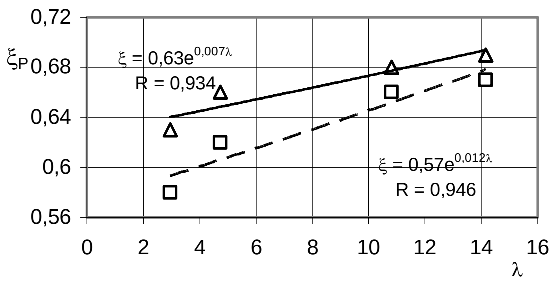

Fig. 8. Shape coefficient of the pearlite colonies, depending on the degree of processing : for the band zone along the side - solid line, for the band zone close to the axis of symmetry – dotted line

The change in the shape coefficient of the ferrite grains and pearlite colonies, depending on the degree of processing of an ingot is depicted in Fig. 7 and 8. The higher the degree of processing , the higher the shape coefficient value. The central zones reach lower values.

3. Characterization of steel properties after applying various degrees of processing

Strength properties of steel of C4D grade increase as the degree of processing increases and in the tested range, they exhibit a linear dependence (Fig. 9). The intensity of increase of the conventional yield point is larger than of the tensile strength.

Plastic properties of steel exhibit various tendencies as the degree of processing increases. Elongation (A_5) decreases and contraction (Z) decreases slightly, amounting on average to about 80% (equations 1, 2).

Strength and plastic properties of steel of S355J2 grade, determined in static tensile test on round samples ϕ 10 mm, change in a linear way together with the degree of processing (Fig. 10 and equations 3, 4), analogically as in the case of ferritic steel.

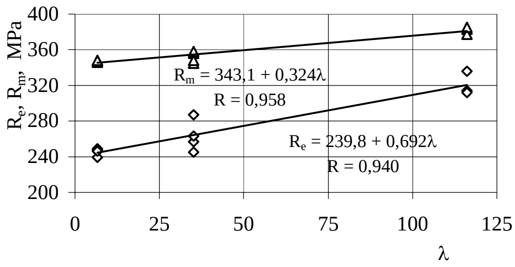

Fig. 9. Strength properties of ferritic steel, depending on the degree of processing

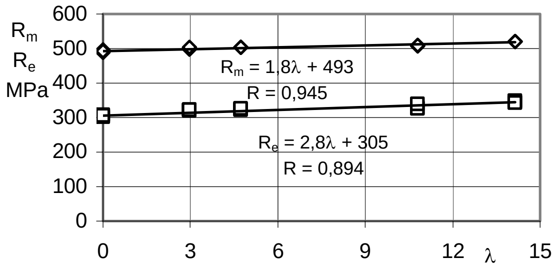

Fig. 10. Strength properties depending on the degree of processing of the F-P steel

The obtained increase of strength properties is a result of homogenizing and size reduction of structure, and in particular, of ferrite grains and pearlite colonies. Contraction increases slightly from about 69% to 73%, whereas relative elongation A_5 exhibits smaller increase, of the order of 0,5-2%

$$A_5=45.4 - 0.108\times\lambda \quad (1)$$
$$Z=80.6 - 0.011\times\lambda \quad (2)$$
$$A_5=0.15\lambda + 32.4 \quad (3)$$
$$Z=0.29\,\lambda + 68.7 \quad (4)$$

4. Conclusions

The structure and properties of steel after hot rolling of a continuous ingot made of low-carbon steel and after air-cooling, significantly depend on the degree of processing. The surface area of flat ferrite grain, steel of C4D grade, decreases until it reaches a degree of processing λ =30. With its further increase (λ =30-115), ferrite grain remain at a steady level of about 320 μm^2 (Fig. 2). The coefficient of ferrite grain shape increases as the degree of processing increases (Fig. 3). The higher the degree of processing, the more equiaxial the shape of grains. Strength properties of the steel increase as the degree of processing increases and in the tested range, they exhibit a linear dependence. The A_5 elongation decreases and the contraction remains at a steady level of 80%.

After the hot rolling process of the continuous ingots of steel of S355J2 grade within the range of the degree of processing λ =2.97-14.15, a structure of ferritic-pearlitic steel with heterogeneous distribution on the cross-section was revealed (Fig. 4). In a zone located at a distance of 5 mm from the band's side, the cross-section area of ferrite grain and of pearlite colony was smaller than in the zone close to the axis of symmetry. This difference was stable for the tested degrees of processing. After ingot processing amounting to λ = 3, the average cross-section area of ferrite grain and of pearlite colony equalled 320-370 μm^2 and 300-350 μm^2, respectively. After rolling reduction of ca. λ = 14, the respective fields were twice smaller. The determined coefficient of ferrite grain and pearlite colony shape increases as the degree of processing increases (Fig. 7 and 8). The higher the degree of processing, the more equiaxial the shape of grains. Strength properties of the steel increase as the degree of processing increases and within the tested range, they exhibit a linear dependence. The intensity of increase of the conventional yield point is higher than of the tensile strength. Together with an increase in the degree of processing, elongation A_5 and contraction increase gently.

The finding of the quantitative relations between the degree of processing , the structure and properties allows for predicting the minimal value of the degree of processing, which should guarantee obtaining the required structural features and consequently, product's functional properties.

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