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INFLUENCE OF RECRYSTALLIZATION ANNEALING ON THE PROPERTIES AND STRUCTURE OF LOW-CARBON FERRITIC STEEL IF

This paper shows results of researches of a structure and mechanical properties of metal sheets of IF steels subjected to recrystallization annealing. The annealing was held in the scope of the temperature of 600-900°C over 25 min time. The impact of heat treatment on changes of properties and structure of the researches steel has been analysed. During annealing typical processes of rebuilding of the structure deformed as a result of cold deformation in the form of forming new recrystallized grains and their growth were observed. As the temperature of annealing increases the hardness of the material gradually decreases.

Keywords: low-carbon IF steel, annealing, mechanical properties, microstructure

1. Introduction

Since many years steel has been used as a basic construction material in the automotive and railway industry. Despite development of new materials, which aim is to decrease weight of construction elements, in the nearest future this situation is not going to change. The reason is that steel, obtained in well known, proven, and mastered technological processes, has stable physical and mechanical properties [1,3]. According to current state of knowledge construction steels for the automotive industry can be divided into three basic groups:

I. soft, plastic low-carbon steels (DQSK – *Deep Quality Special Killed*, IF – *Interstitial Free*) with tensile strength R_m below 300 MPa and total elongation A in the scope of 30÷60%;

II. steels with high strength – HSS – High *Strength Steel* (BH – Bake*Hardening*, CMn – Carbon *Manganese*, IF – Interstitial *Free* with micro additions, HSLA – *High Strength Low Alloy*) with tensile strength over 300 MPa;

III. advanced steels with very high strength – AHSS – *Advanced High Strength Steels* (R_m over 700 MPa, reaching even 2000 MPa) and elongation in very wide borders of 5÷30% [2,10].

Those two abovementioned groups can be called classical: those materials are widely used to build bodyworks of vehicles in mass production. The steels form the third group are being gradually implemented into production and their share systematically grows. This is due to exceptionally high degree of deformation while maintaining high strength of those materials. Currently on less significant elements of bodywork mostly conventional low-carbon steels are used, such as steels obtained by hot and cold rolling. This group may include ferritic low-carbon IF steel which does not contain interstitial elements, i.e. carbon and nitrogen, in solid solution. This material is characterized by good plastic properties and high susceptibility to pressing [2,11].

Technology of obtaining thin metal sheets of IF steels consist of three consecutive processes: hot rolling in austenite range (above A_3 temperature) with large drafts, cold rolling in ferrite range and recrystallization annealing. The last stage is very important due to the further use of this material [4-9,12]. In recent years, the interest in using unconventional SPD methods to obtain materials with ultra-fine-grained structure has significantly increased. Grain subdivision promotes primarily the increase of strength properties of material. Such methods include DCAP (Dissimilar Channel Angular Pressing), AARB (Asymmetrical Accumulative Roll Bonding), and DRECE (Dual Rolls Equal Channel Extrusion). Increasing mechanical properties while maintaining good plastic properties may increase the potential use of IF steel in new areas, including aviation and defence industries [13].

This paper presents results of studies on the influence of parameters of recrystallization annealing on change of mechanical properties and structure of cold rolled metal sheets of IF steels.

2. Material and methodology

The researched material was low-carbon ferritic IF steel in the form of a metal sheet with 2 mm thickness after cold rolling. Chemical composition of this researched steel is shown in Table 1.

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TABLE 1

Chemical composition of IF steel (wt.%)

C	Mn	Si	Cr	N	Cu	Al	V	Ti	S, P
0.002	0.12	<0.005	0.019	0.005	0.02	0.029	0.001	0.059	≤17

Samples measuring 15×10×1 mm were taken out of the sheets and then they were annealed in a laboratory chamber furnace ELF11 type at a heating rate of 10°C/min. Annealing was held in the temperature of 600-900°C with holding time of 25 min and cooling in the air. The scheme of recrystallization annealing is shown in Figure 1.

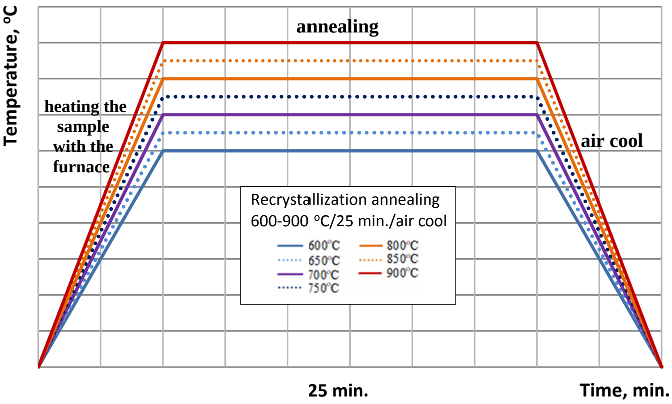

Fig. 1. The scheme of recrystallization annealing

Hardness measurement was held on a longitudinal polished section using a ZWICK 3212002/00 type hardness tester and Vickers method with a load of 10 N (HV1).Metallographic examination of samples in the state after cold rolling and after annealing was performed with usage of an Olympus GX71 light microscope.

The evaluation of a size of a ferrite grain has been carried out with the MetIlo® programme using microstructural binary images (Fig. 2a, 2b). The actual area of analysis was 0.577 mm^2. The size measure of a grain and the value of an average grain diameter was taken. A classic shape index and an average number of grains in a mm^2 were also determined. In order to reveal the microstructure the polished sections were etched twice with different reagents – Vielle's reagent (5 ml of HCl + 1g of picric acid + 200 ml of 95% ethanol) + 1 ml HF and Marshall's reagent (8g of oxalic acid + 5ml of H_2SO_4 + 100 ml of H_2O + $H_2O_2$30%) + 1 ml of HF. Etching with Marshall's reagent allowed to reveal grain boundaries and was necessary to perform a quantitative analysis of the structure.

3. Result of studies

If steel after cold rolling was characterized by a monophasic ferritic structure. Ferrite grains elongated in the direction of rolling are clearly visible. Annealing at the temperature of 600°C did not cause a significant change in the deformed structure. Ferrite grains elongated in the direction of rolling are clearly visible. After heat treatment at the temperature of 700°C and 800°C the structure is partially recrystallized and at a higher heat treatment temperature grain growth occurs (Fig. 3a-3j).

Hardness of the HV1 material after cold rolling is 158. As a result of heat treatment hardness decreases by approximately 6% for annealing at the temperature of 600°C and 20% for annealing at the temperature of 700°C. For annealing at the temperature of 800°C hardness has been reduced by 47% in relation to the initial cold rolled sample. A further increase in annealing temperature slightly affects the change in the level of hardness (Table 2).

The average diameter of a grain D_s in the material after cold rolling is 28.9 µm. This parameter slightly changes after annealing at the temperature of 600-650°C. Heat treatment at 700°C caused growth of the average grain boundary by 53% in relation to the initial cold rolled sample. As the temperature increases a further increase in the average diameter of the grain is noticeable. At the annealing temperature of 900°C it is 59.2 µm (Table 3). The higher D_s value the lower hardness of tested

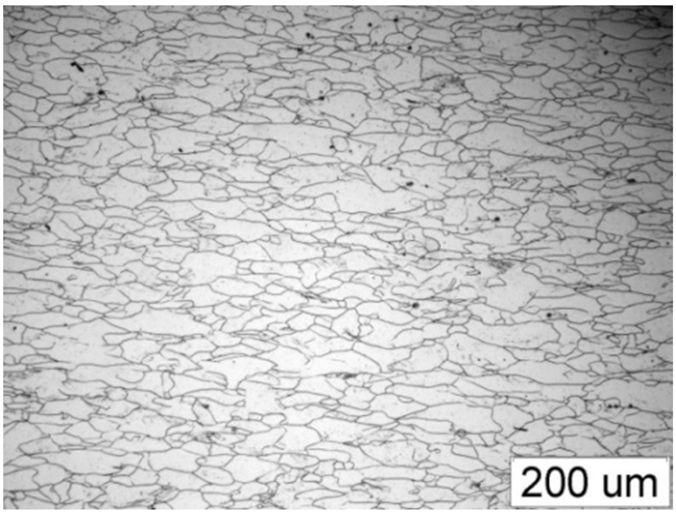

Fig. 2a. Gray image of microstructure of IF steel in the state after cold rolling – etched with Marshall's reagent + HF

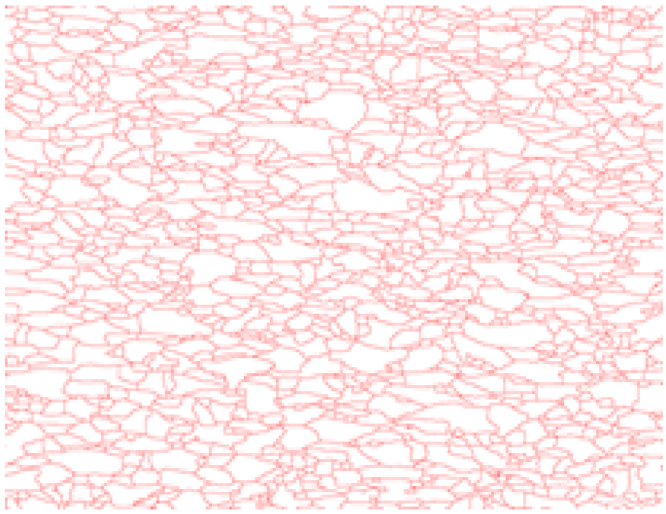

Fig. 2b. Binary image of microstructure of IF steel in the state after cold rolling

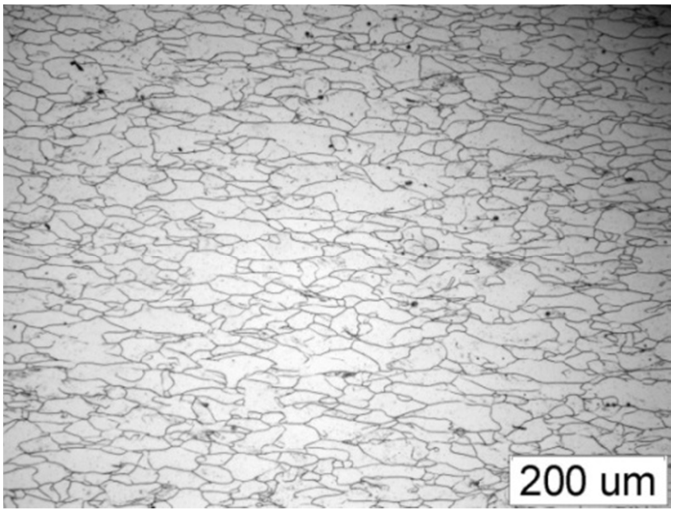

Fig. 3a. Microstructure of IF steel in the state after cold rolling[1.)]

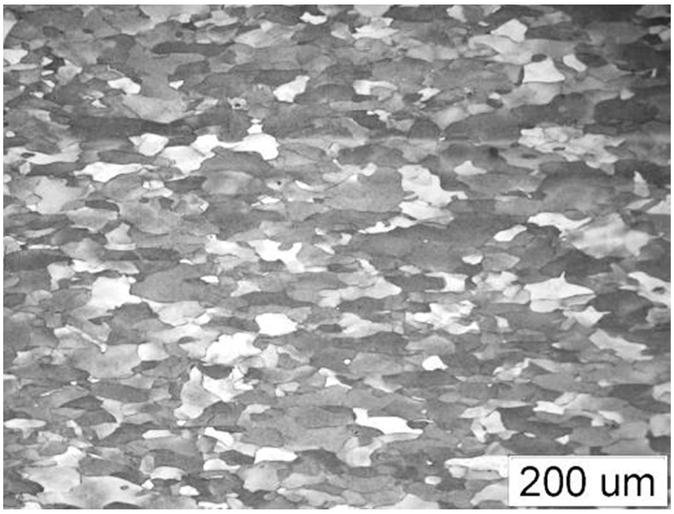

Fig. 3b. Microstructure of IF steel in the state after cold rolling[2.)]

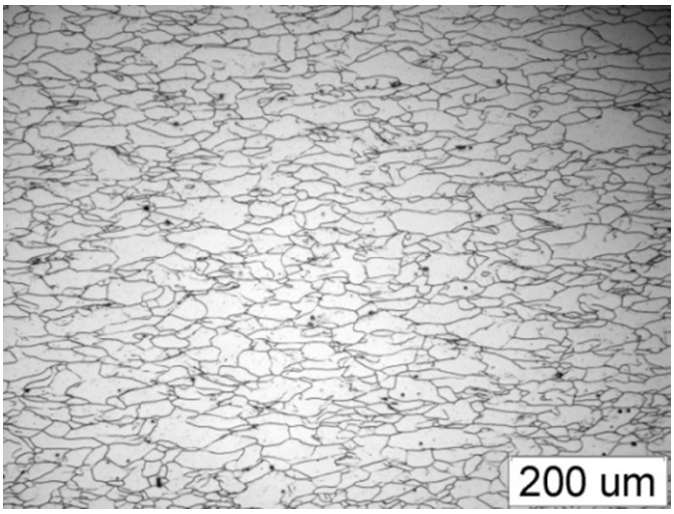

Fig. 3c. Microstructure of IF steel after annealing at the temperature of 600°C/25 min[1.)]

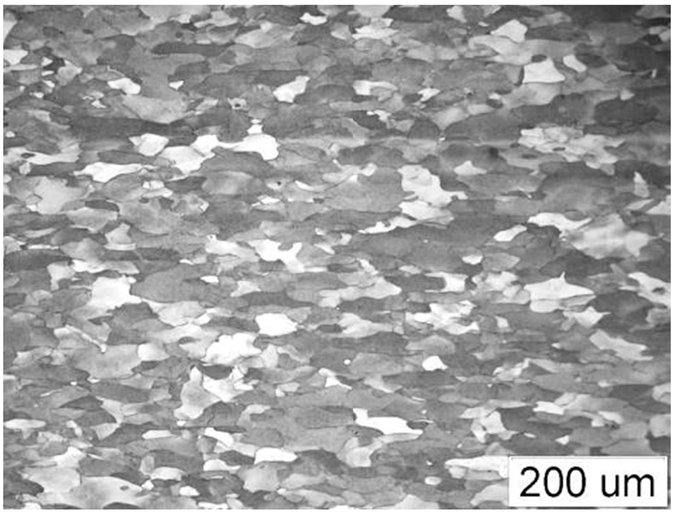

Fig. 3d. Microstructure of IF steel after annealing at the temperature of 600°C/25 min[2.)]

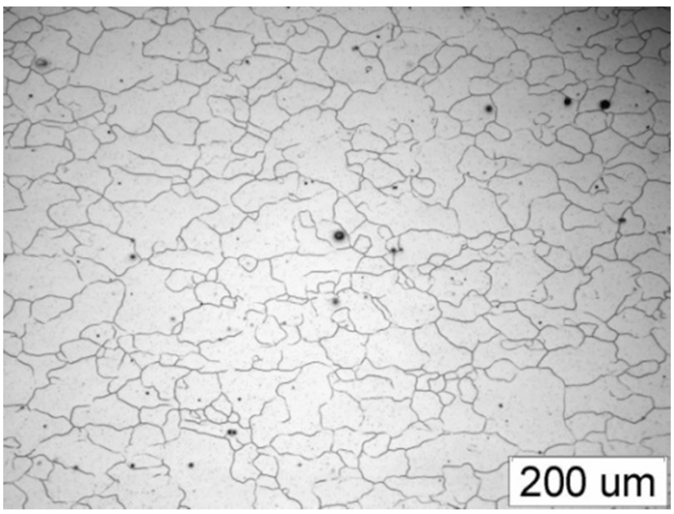

Fig. 3e. Microstructure of IF steel after annealing at the temperature of 700°C/25 min[1.)]

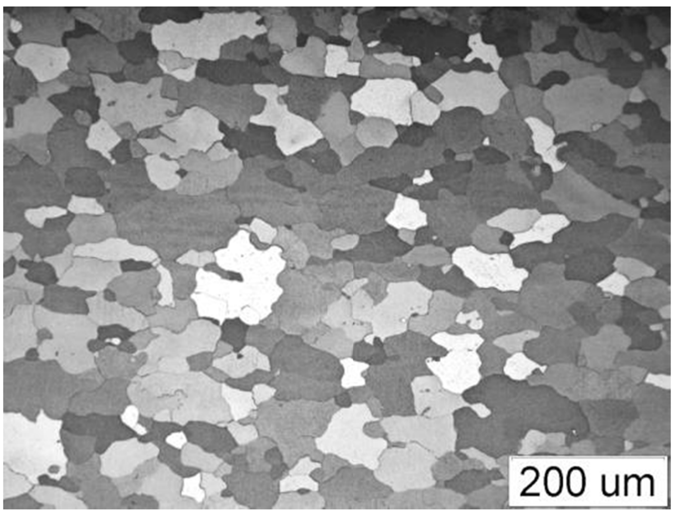

Fig. 3f. Microstructure of IF steel after annealing at the temperature of 700°C/25 min[2.)]

[1.)] metallographic polished sections etching with Marshall's reagent + HF.
[2.)] metallographic polished sections etching with Vielle's reagent + HF.

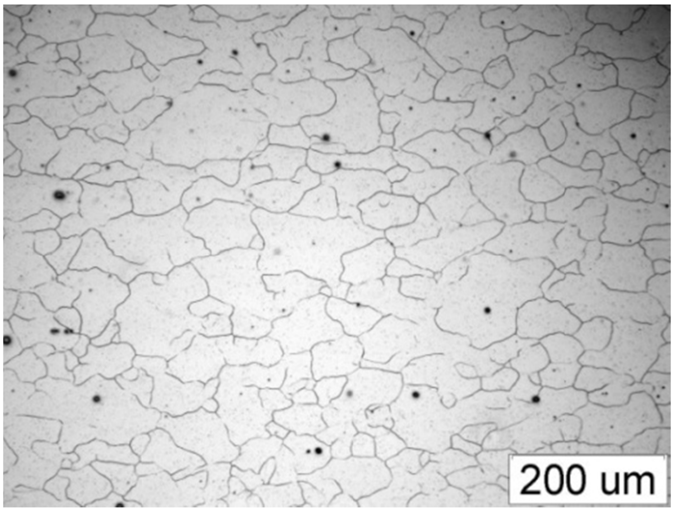

Fig. 3g. Microstructure of IF steel after annealing at the temperature of 800°C/25 min[1.)]

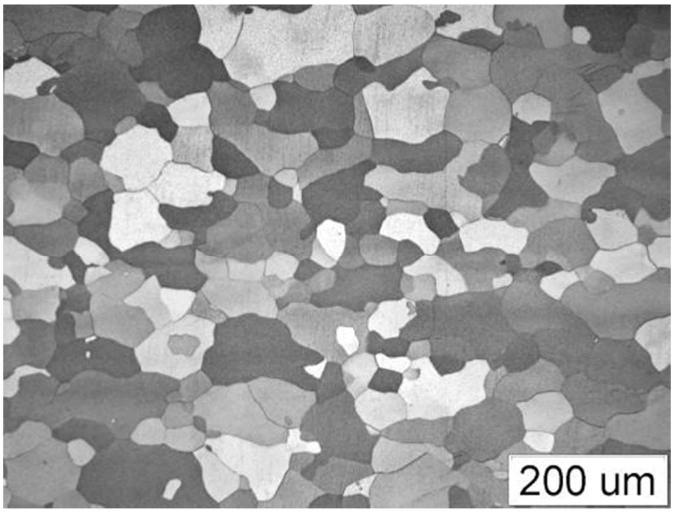

Fig. 3h. Microstructure of IF steel after annealing at the temperature of 800°C/25 min[2.)]

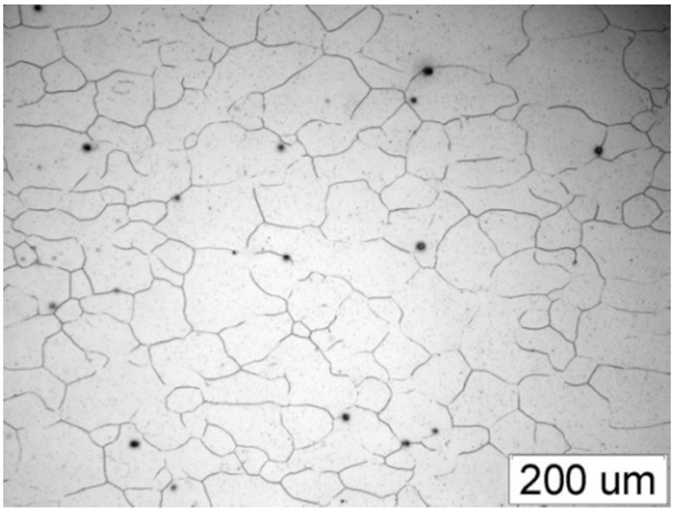

Fig. 3i. Microstructure of IF steel after annealing at the temperature of 900°C/25 min[1.)]

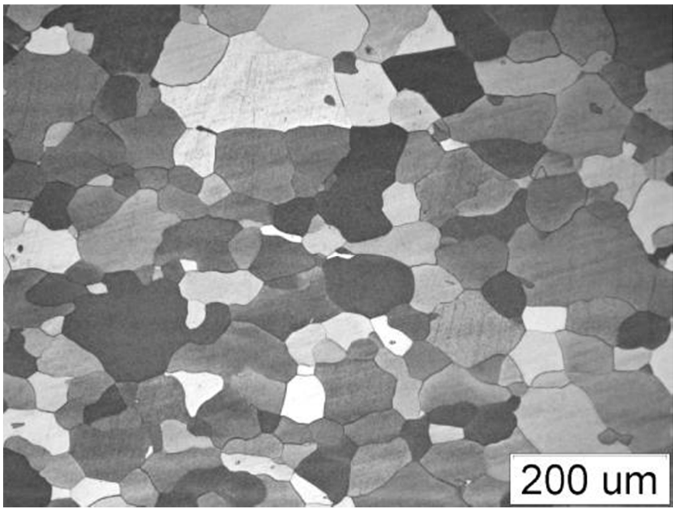

Fig. 3j. Microstructure of IF steel after annealing at the temperature of 900°C/25 min[2.)]

material. This dependence is shown in Fig. 4. The shape index at the highest annealing temperature is 0.701 (Table 3 and Fig. 5). According to literature data if the value of the shape index tends to oneness grains take a shape similar to a sphere [14].

TABLE 2

HV1 hardness after cold rolling and recrystallization annealing

Annealing	**HV1 Hardness**
State after cold rolling	158
600°C/25 min/air	149
650°C/25 min/air	146
700°C/25 min/air	126
750°C/25 min/air	93
800°C/25 min/air	84
850°C/25 min/air	81
900ºC/25 min/air	78

TABLE 3

Quantitative analysis of the structure

Annealing	**Average number of grains in a mm^2 [1/mm^2]**	**Average diameter of a grain [µm]**	**Average index of a shape**
State after cold rolling	2063	28.9	0.576
600°C/25 min/air	2049	28.5	0.606
650°C/25 min/air	1971	27,3	0,627
700°C/25 min/air	705	44.5	0.639
750°C/25 min/air	689	48,9	0,661
800°C/25 min/air	521	52.5	0.672
850°C/25 min/air	404	58,4	0,684
900ºC/25 min/air	398	59.2	0.701

[1.)] metallographic polished sections etching with Marshall's reagent + HF.
[2.)] metallographic polished sections etching with Vielle's reagent + HF.

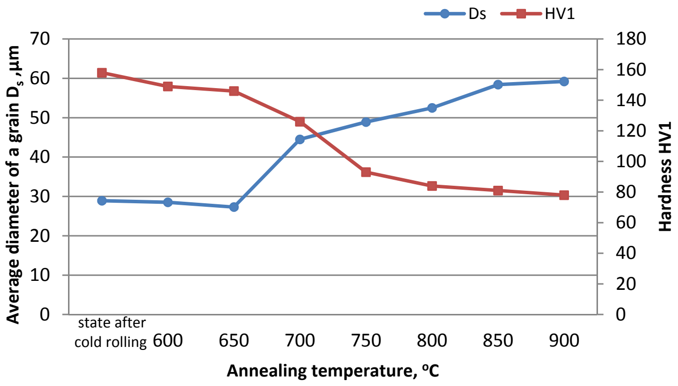

Fig. 4. Influence of the annealing temperature on the average diameter of a grain and Vickers hardness

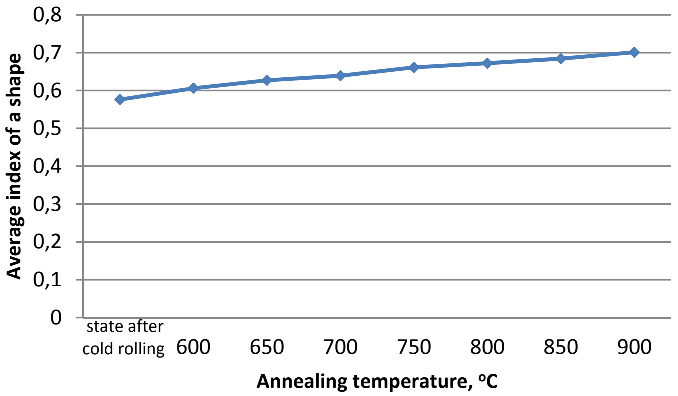

Fig. 5. Influence of the annealing temperature on the average index of a shape

4. Conclusion

During the recrystallization annealing process the structure of the studied steel changes. Recovery and recrystallization processes occur which remove effects of a cold work. The most favourable structure is obtained after annealing at 800°C. If the temperature is higher the recrystallized grains grow. It has been shown that as the temperature of annealing increases the hardness of the material decreases. For annealing at the temperature of 800°C hardness has been reduced by 47% in relation to the initial cold rolled sample. A further increase in annealing temperature slightly affects the change in the level of hardness. The obtained results of the quantitative analysis of the structure indicate a change of grain size and shape during the annealing process. The value of average grain boundary D_s after annealing at the temperature of 800°C doubled in relation to the D_s value of cold rolled initial sample. It means that equaxial grains have appeard in the recrystallized structure. The shape index tends to oneness. These studies were a basis to develop heat treatment diagram of tested steel to its further deformation with SPD methods.

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