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ANALYSIS OF THE POSSIBILITIES OF USING FORGING HEAT IN ISOTHERMAL ANNEALING PROCESSES FOR AISI 4140 ALLOY

Production processes of hot forging most often look similar [1-3]. Forging in several operations, usually in three or four. Most often the first operation is upsetting or flattening (sometimes rolling). The last operation is finishing forging. This applies to the production of steel forgings for the automotive, agricultural and other similar industries. Typical production proceeds as follows: the forgings are cleaned (shot-blasted) and then heat treatment is performed. It can be normalization, hardening and tempering, etc. After the heat treatment, forgings are checked and subjected to strength and microscopic tests, hardness tests, impact tests. The type of tests depends on the recipient. The process described in the work takes place in three operations. The heat treatment used so far is hardening and tempering. An attempt was made to change the heat treatment technology for a selected product made of 42CrMo4 steel (1.7225) (4140). An isothermal annealing test was carried out at different temperatures and for different times. The possibility of using heat from the forging process in heat treatment processes for the described product has been confirmed.

Keywords: AISI 4140 steel, isothermal annealing, forging, thermal treatment

1. Introduction

All forgings produced must meet the specific properties specified by the customer [12]. Mechanical properties depend on the microstructure. Depending on the chemical composition of a given steel grade, heat treatment is carried out: annealing, quenching and tempering, or supersaturation and aging. Generally, the heat treatment is carried out after the forgings reach the ambient temperature. However, attempts are being made to combine the plastic shaping process with heat treatment [13]. This type of combination sometimes gives slightly better properties than conventional heat treatment.

Conventional heat treatment sometimes forces the material to heat up to >A1 or / and >A3 several times. In addition, the second variable is time. It should be remembered that for conventional heat treatment the production time is definitely longer [14]. That is why one of the alternatives is thermoplastic treatment. We can then use the heat from the hot forging process. Consequently, this eliminates the need to cool products to ambient temperature. [8]

Research in this field is fully justified, because for obvious reasons they will bring many benefits, both scientific and financial. In the literature, you can find many items and studies related to research on the use of thermoplastic processing, which compare the obtained properties and process economics with traditional methods. The authors of [9] compare the properties of manganese sheets with the addition of Nb and Ti produced in the conventional process and in the process of energy-saving thermoplastic processing line. The correctness of the approach to the subject is also confirmed by the results of the work [10] concerning the machining of micro alloy steel. Forgings produced by thermoplastic method were tempered in the temperature range from 550ºC to 650ºC. As a result, the following properties were obtained: Rp0,2 – from 993 to 925MPa, Rm – from 1061 to 978MPa and KV-40 from 60 to 69J.

The aim of the work are preliminary research results obtained on a semi-industrial heat treatment prototype line. The results of the work were compared with conventional heat treatment. The scope of research concerned the microstructure, torsional strength and hardness of the analysed forgings.

The conventional forging process for forged hot steel forgings looks as follows [4-7,15]:
- material preparation (cutting),
- heating (induction, gas, etc.),
- initial forming (upsetting, flattening, bending, elongation, etc.),
- matrix forging,

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– die forging finishing,
– trimming, punching, punching, etc.

Few data in the literature can be found regarding heat treatment using heat forging. The author conducts research on the use of forging heat in heat treatment processes, normalizing annealing and isothermal annealing. The following work presents the results of research on the use of forging heat in the isothermal annealing process of 42CrMo4 steel forgings (AISI 4140). The chemical composition of the steel tested is given in the table.

TABLE 1

The chemical composition in wt% of AISI 4140 steel used in forging process

C	Mn	Si	P	S	Ni	Mo	Cr	Fe
0,38-0,45	0,6-0,9	Max 0,4	Max 0,025	Max 0,025	—	0,15-0,30	0,9-1,20	the rest

2. Process description

The process of hot forging of 42CrMo4 steel is performed in three operations (Fig. 1): flattening, forging, finishing forging. After the forging process, the forging is trimmed and cooled freely to the ambient temperature. Then the forgings are hardened and highly tempered to obtain a hardness in the range 250-280 HB. At this point, the author proposed a change in technology and the use of heat from the forging process (Fig. 2) and the development and selection of heat treatment parameters in order to obtain a final product that meets the requirements of the recipient. Below is a schematic diagram of the technology used to date and a proposal for changes in the heat treatment. It should be noted that the products made in the current technology and made in the new meet the requirements of the ordering party.

3. The temperature of the forging and preform material

At the stage of implementation of the research in this field was able to be examined actual forging temperature by using high-speed (250 Hz), temperature recording thermocouple type K was placed in the material before flattening operation – Fig. 4. The results of the infrared camera is shown in Fig. 3.

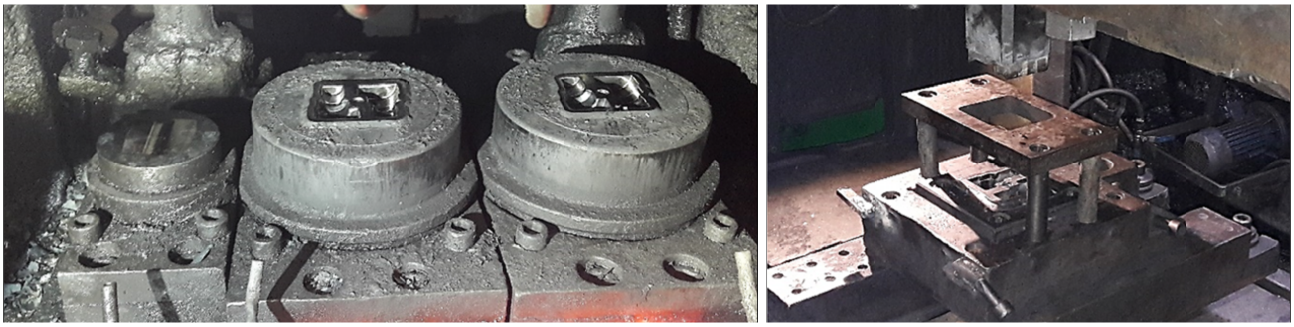

Fig. 1. General appearance of tools for forging in 3 operations and forging after forging

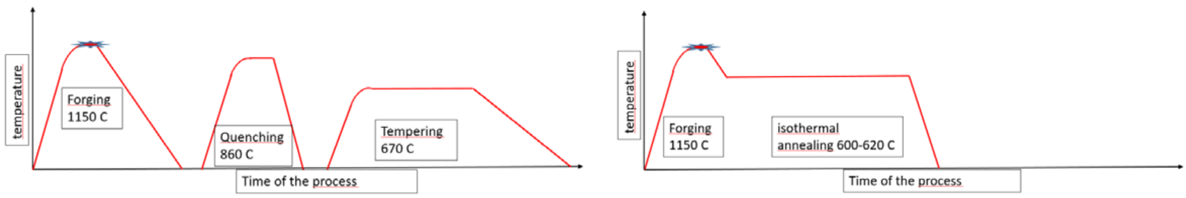

Fig. 2. Diagram of currently used typical technology and new after changes using forging heat

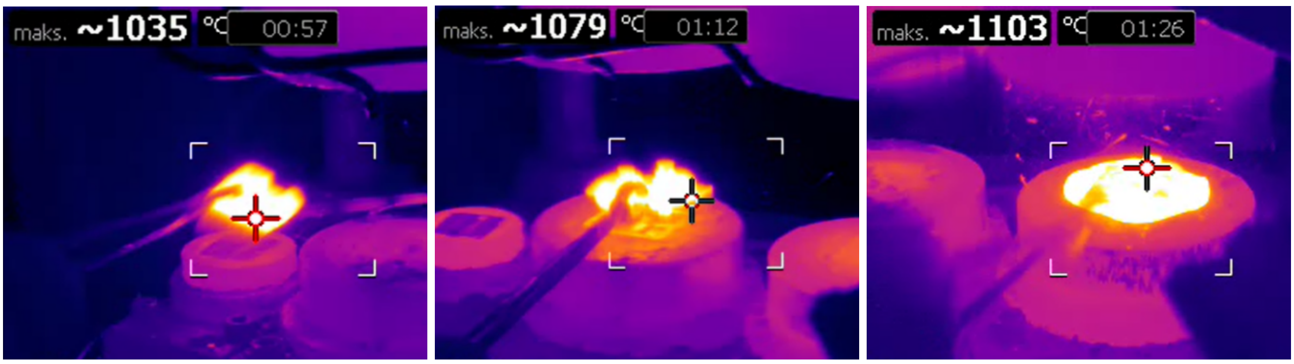

Fig. 3. Temperature of the forging after each forging operation

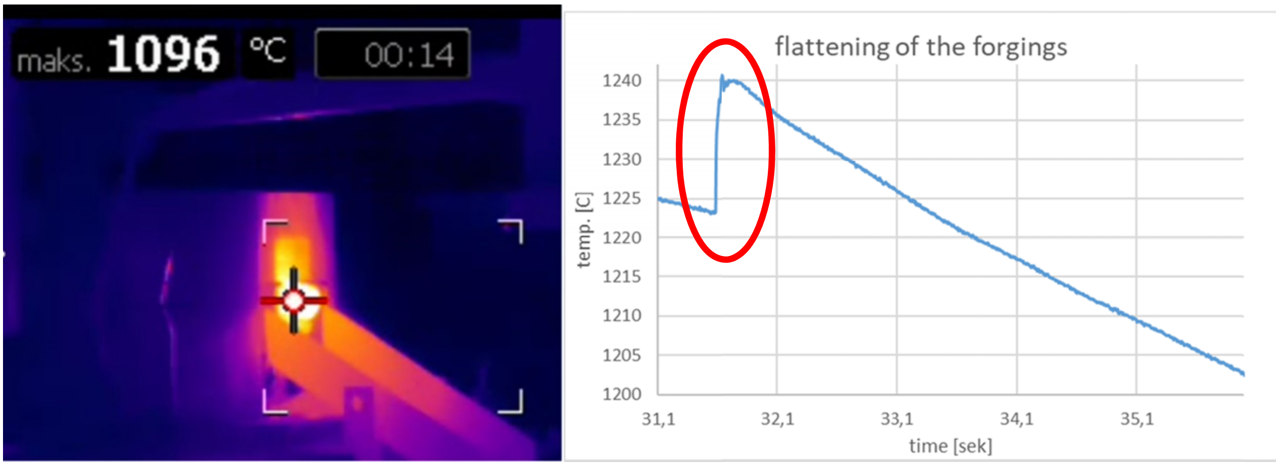

Fig. 4. Temperature after leaving the heater and temperature before and during forging

A much higher temperature was observed than those recorded on the surface of the blank and forging. The temperature read by the pyrometer was about 1100°C. IRD camera also gave this temperature. In contrast, the temperature read from the thermocouple is 1225°C, and when forging is 1240°C. Despite the slight increase in temperature, no Widmanstatten structure was found.

In order to obtain the required properties for the finished product (Fig. 5), a series of studies on the influence of temperature and isothermal annealing time for the 42CrMo4 steel forgings were carried out. The work presents the most interesting results of the analyzes carried out. The temperature range of the tests was 580-680°C and annealing time 1.0 h.

Figure 6a shows the pictures of the rod microstructure in the delivery state – a structure containing very small Fe_3C secretion in a spheroidal form. Figure 6b shows the visible structure of the forging cooled in the air.

Figure 6c shows the microstructure after heat treatment – (hardening + high tempering), visible sorbitol structure with fine spheroidal secretions. Parameters of thermal treatment:

– heating and austenitizing in the range of 820-860°C – 2.0 h,
– tempering in oil at 40°C,
– tempering at 540-678°C – 2.5 h (collection based on 250-280HB hardness measurements Fig. 7-8.).

The most important value and measuring point is area number 2 (Fig. 7). For this area, the hardness value is in the range 275-282 HB. As we can observe, depending on the place, the hardness ranges from 261 to 297 HB.

The results of research on the possibility of using isothermal annealing instead of thermal improvement together with the choice of parameters (time, temperature) are presented below. The proposal to change the heat treatment technology (except for the use of heat from the forging process) was the result of the necessity imposed by the machining of this element. Too much

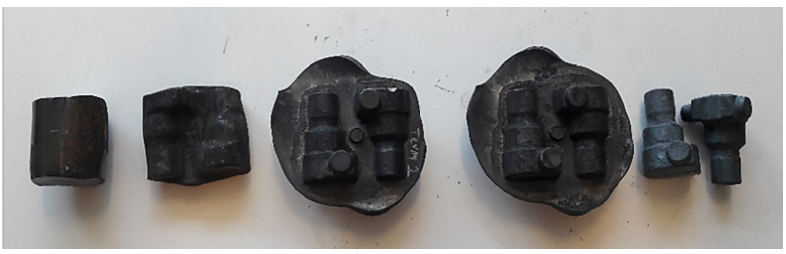

Fig. 5. Appearance of forgings after each forging operation

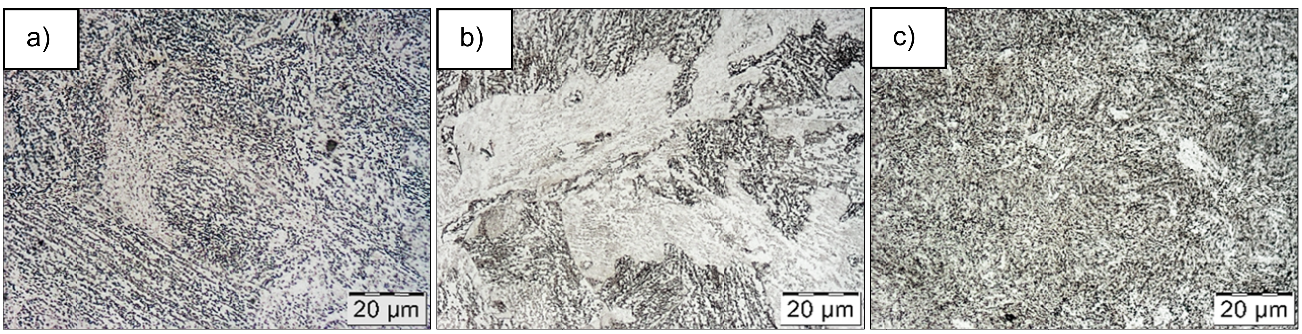

Fig. 6. Microstructure: a) bar in the delivery condition, b) forgings after forging, c) forgings after heat improvement

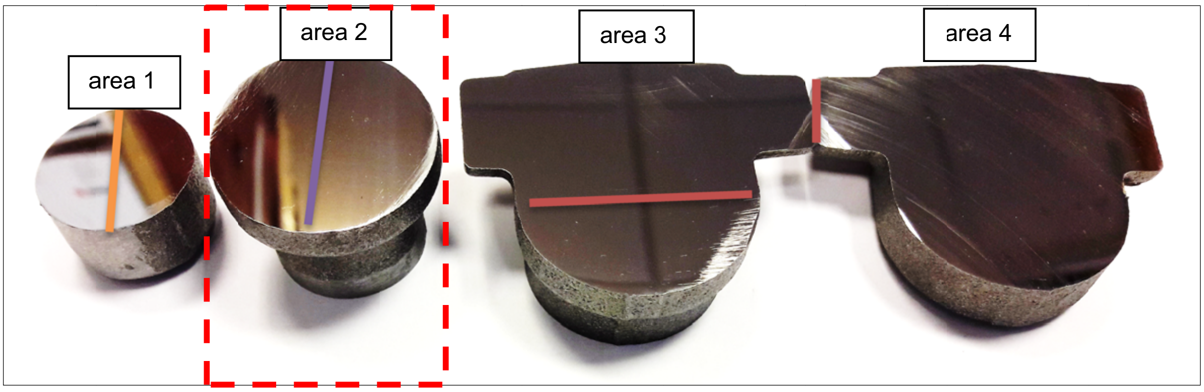

Fig. 7. Locations where hardness measurements are carried out using the Brinell method

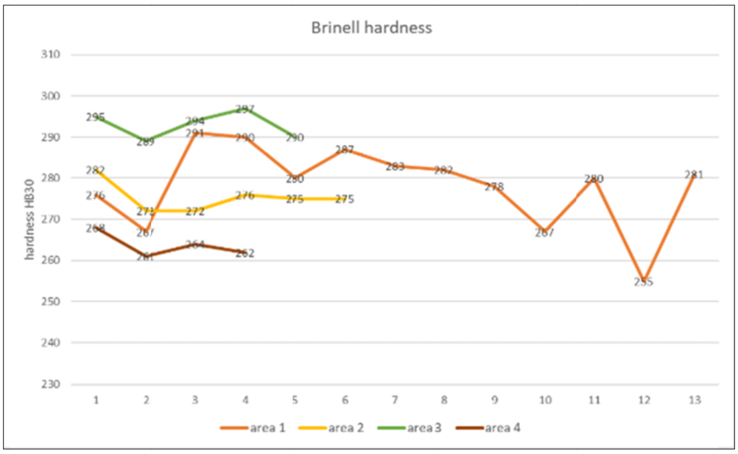

Fig. 8. Hardness distributions for selected forging sections from figure 7

hardness (outside the upper range) caused increased wear of tools for machining (cutters, drills, maybe turning).

4. Isothermal annealing of 42CrMo4 steel forgings

The isothermal annealing process was carried out in industrial and laboratory conditions. The tests showed a very large convergence of results. The temperature of the samples was measured throughout the entire isothermal annealing test. The temperature-time course for various isothermal annealing temperatures is shown on Figures 9-12. The heat treatment time was 1.0 h. For all temperatures.

In Figures 9-12, places where pearlitic transformation occurred at a given temperature were marked. We can observe clear differences in the duration of the change – the time at which it occurs and the speed at which it occurs.

5. Optical microscopic examination of forgings after heat treatment – isothermal annealing

For the parameters of isothermal annealing presented above, heat treatment of 42CrMo4 steel forgings was performed. Each of the analyzed samples was subjected to microscopic examination. Figures 13-19 show the results of optical microscopic examination.

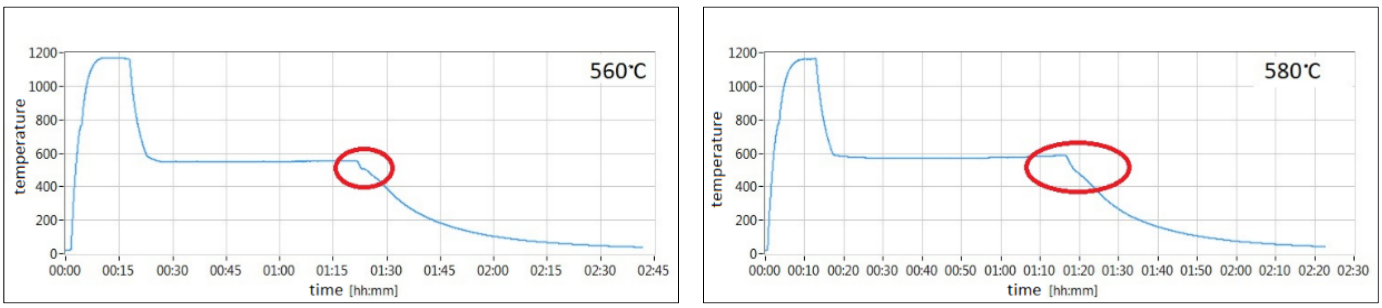

Fig. 9. Heating and cooling curves for isothermal annealing temperature 560°C and 580°C

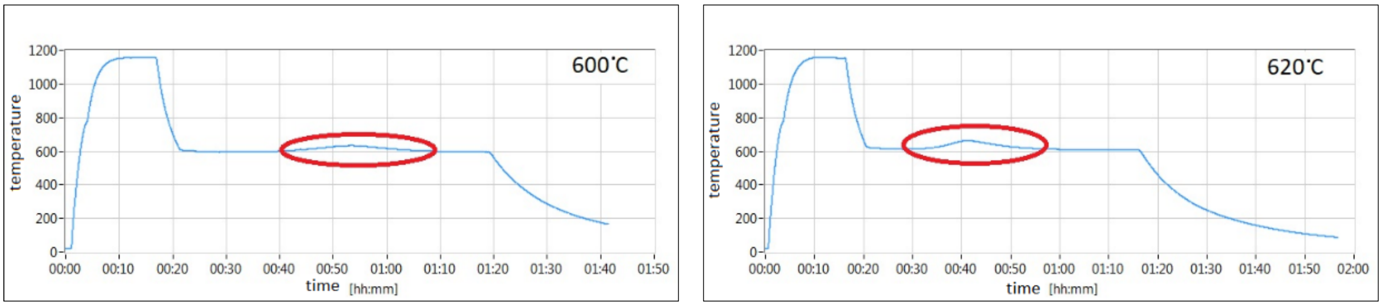

Fig. 10. Heating and cooling curves for isothermal annealing temperature 600°C and 620°C

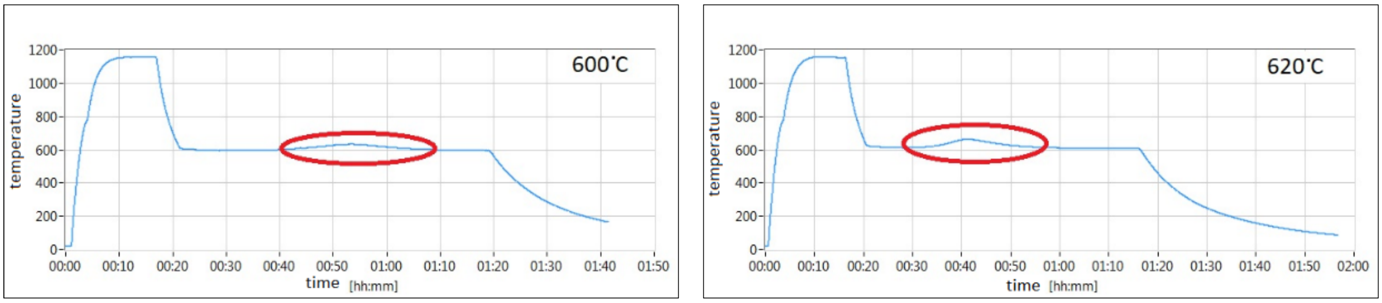

Fig. 11. Heating and cooling curves for isothermal annealing temperature 640°C and 660°C

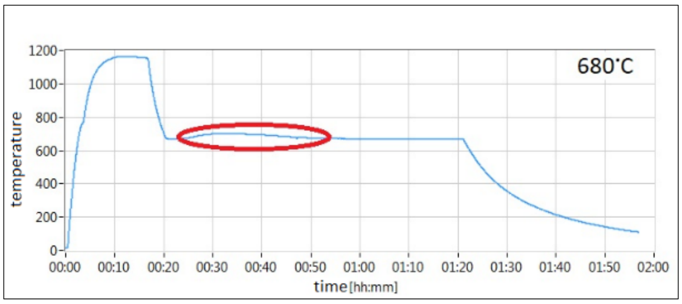

Fig. 12. Heating and cooling curve for isothermal annealing temperature 680°C

The conducted isothermal annealing tests of the 42CrMo4 steel adapter forgings show that for annealing for 1.0 h at 560°C and 580°C at a distance of about 4mm we have a bainitic structure. In areas of greater depth, we can observe emerging perlite grains (dark grains in photos from a microscope). For higher annealing temperatures, apart from the slight decarburization, the structure is perlite with fine ferrite releases.

Figure 20 shows sample microstructures of samples. Pictures were taken at higher magnifications than in Figures 13-19. Place to take pictures of a central area of the analyzed area 2.

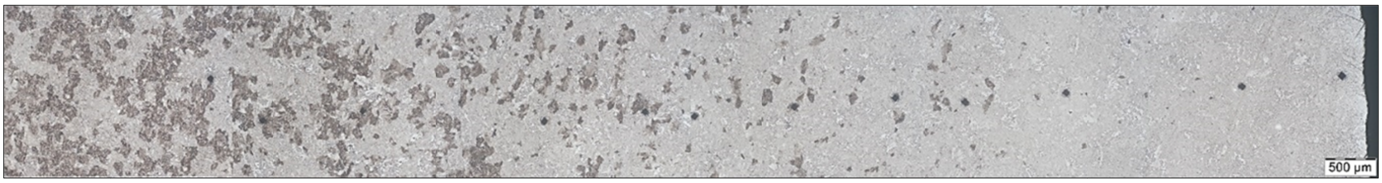

Fig. 13. The microstructure of forgings for the annealing temperature of 560°C and isothermal holding time 1.0 h

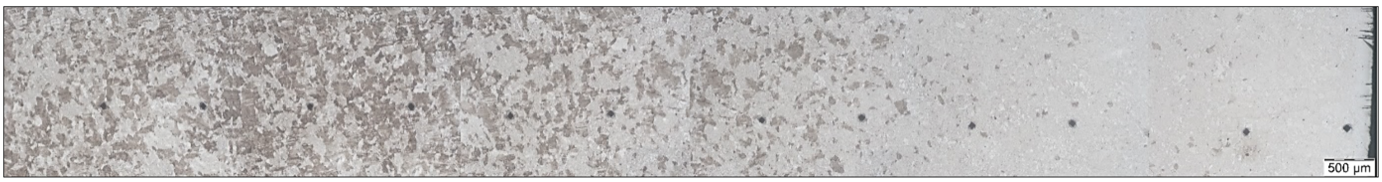

Fig. 14. The microstructure of forgings for the annealing temperature of 580°C and isothermal holding time 1.0 h

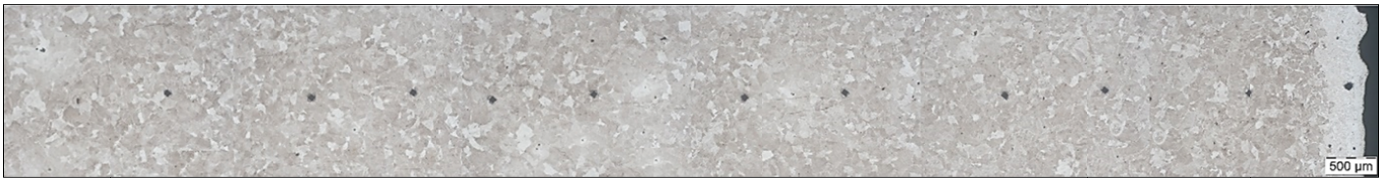

Fig. 15. The microstructure of forgings for the annealing temperature of 600°C and isothermal holding time 1.0 h

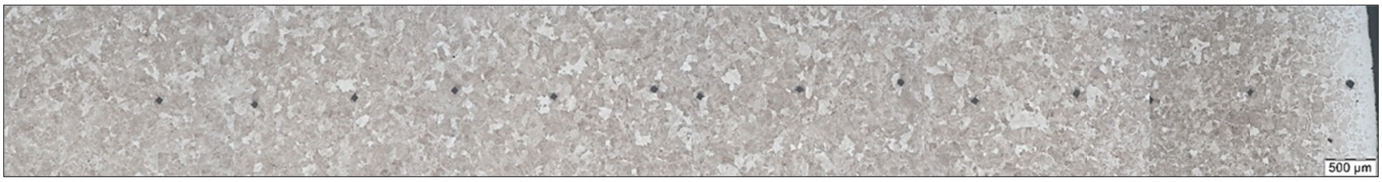

Fig. 16. The microstructure of forgings for the annealing temperature of 620°C and isothermal holding time 1.0 h

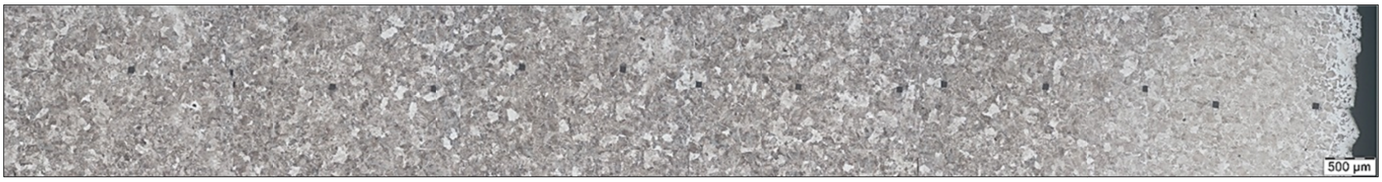

Fig. 17. The microstructure of forgings for the annealing temperature of 640°C and isothermal holding time 1.0 h

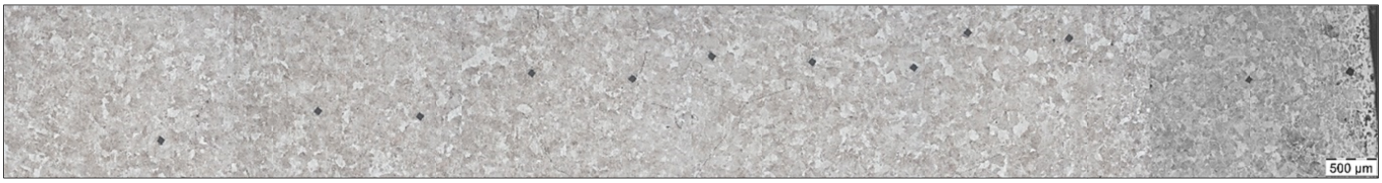

Fig. 18. The microstructure of forgings for the annealing temperature of 660°C and isothermal holding time 1.0 h

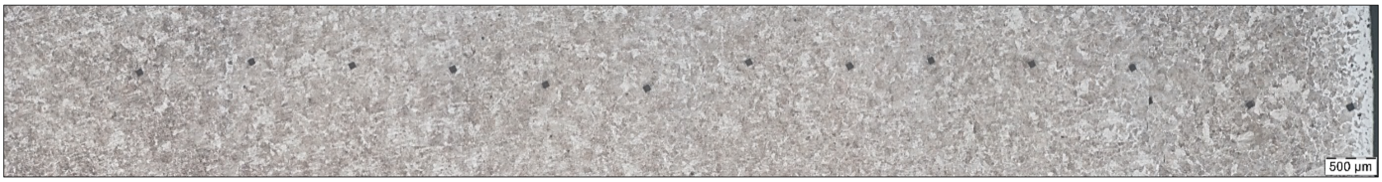

Fig. 19. The microstructure of forgings for the annealing temperature of 680°C and isothermal holding time 1.0 h

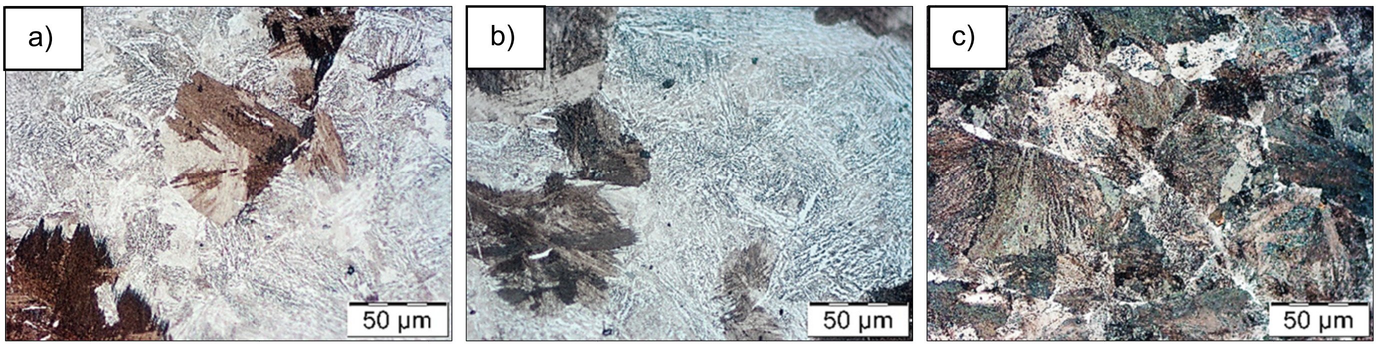

Fig. 20. Microstructure of example forgings after isothermal annealing: a) at 560°C, b) at 580°C, c) at 620°C

For the isothermal annealing temperatures below 600°C, the bulk of the microstructure volume is the upper bainite (bright areas in Figures 11, 12 and 18a and 18b) The rest is perlite and small ferrite separation. For isothermal annealing at 600-680°C, the structure consists of very fine perlite with small ferrite separation over the grain boundaries.

6. Hardness testing and strength tests

In the areas marked as previous as area 2, hardness tests were carried out using the Brinell and Vickers methods. The results of tests and analyses are presented in Figures 21 and 22. As we can observe the requirements for acceptance, they meet forgings whose heat treatment of isothermal annealing were carried out at 600°C and 620°C in 1.0 h.

The average hardness for isothermal annealing forgings at 600°C was 275 HB, and for annealed forgings at 620°C the average hardness was 265 HB. Both of these values are within the 250-280 HB forging receipt.

Strength tests were also carried out for verification. Test samples were made from the analyzed forgings. Plastometric tests were performed at room temperature (torsional strength). The thermally improved and isothermally annealed specimens showed similar strength σ_{ps} = approx. 1060 MPa for deformation ε_{ps} = 0.88.

7. Conclusions

The use of a modern method of manufacturing forgings using heat from the forging process gives very promising results. Possibility of big savings in both time and energy – one heating in the case of isothermal annealing. The results obtained in the isothermal annealing tests show that the annealing at temperatures of 600-620°C in 1.0 h meets the hardness requirements for the adapter type forgings. Specific pearlitic structure with low hardness, easy machining. The author is working on the introduction of a different type of heat treatment using heat forging: thermal improvement and normalization. Preliminary studies indicate the reasonableness, good results and profitability of using this type of treatment. The only condition is to place a heat treatment line near the production sockets (forging and trimming presses). By comparing the results obtained with the results of e.g. V. Pidvysots'kyy [11], we can draw similar conclusions. Especially when we talk about transition temperatures. Traditional

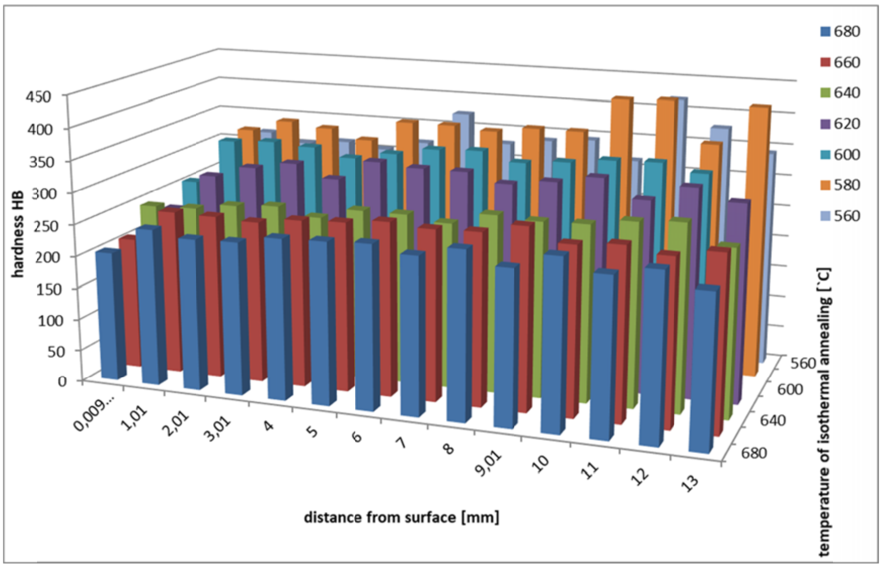

Fig. 21. The results of hardness measurements on cross-sections of the tested samples in area No. 2

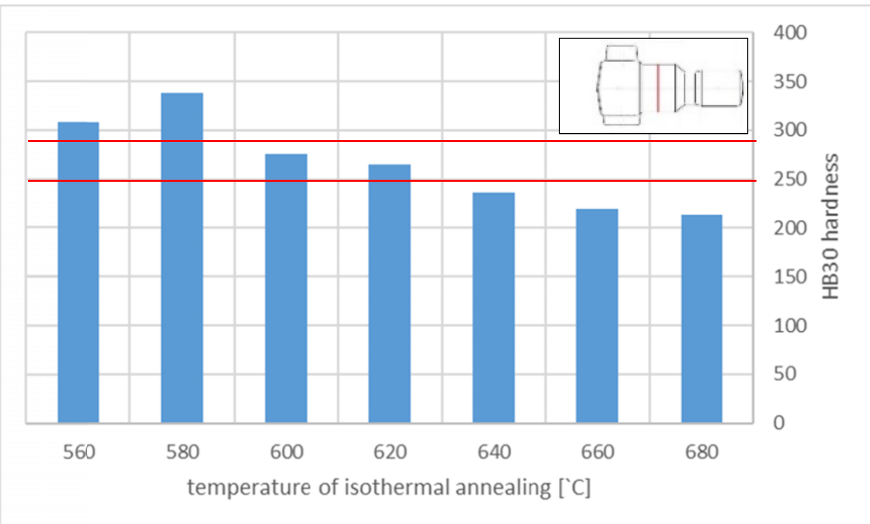

Fig. 22. Medium hardness obtained by Brinell method for the analyzed forgings as a function of annealing temperature

TTT diagrams are performed on the basis of experiments with a constant cooling rate. The determination of process data requires modelling and experimental analysis and selection of heat treatment parameters for the appropriate product. In addition, it should be remembered that the condition of the microstructure after heat treatment has an austenite grain size. The grain size affects the kinetics of phase transitions.

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