Heat Treatment of Cold Formed Steel Forgings

Toplotna obdelava hladno preoblikovanih jeklenih odkovkov

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Abstract: For economical production of cold formed steel forgings for the automotive industry it is important that they have a long working life. Their corresponding mechanical and thermal properties are achieved by a heat treatment process.

In the Slovenian company ISKRA Avtoelektrika they manufacture, with the processes of cold forming, a great number of a different steel forgings for the Slovenian and European automotive industry. During their exploitation they are exposed to the high mechanical and temperature loads.

A practical example is presented an optimisation of the heat treatment procedure for typical steel forging (pinion) from the ISKRA Avtoelektrika production program.

The practical result of the used heat treatment are (the cold formed) steel pinions with the surface hardness of approximately $HRc = 65$, and the case hardened depth of the surface layer with the hardness higher than 551 $HV1$ approximately 0.7 mm.

On the basis of the results of corresponding economical studies, supported by technical investigations and analysis, second device (of the same producer, type and capacity) for the heat treatment was installed.

Professional paper

Izvleček: Za ekonomično proizvodnjo hladno preoblikovanih jeklenih odkovkov za avtomobilsko industrijo je pomembno, da imajo le-ti dolgo obratovalno dobo. Njihove visoke mehanske in toplotne lastnosti se dosežejo s postopki toplotne obdelave.

V podjetju ISKRA Avtoelektrika, d. d., izdelujejo s hladnim preoblikovanjem veliko število različnih jeklenih odkovkov za slovensko in evropsko avtomobilsko industrijo. Odkovki so med svojo eksploatacijo izpostavljeni velikim mehanskim in toplotnim obremenitvam.

Kot primer je predstavljena optimizacija procesa toplotne obdelave tipičnega jeklenega odkovka (pastorka) iz proizvodnega programa ISKRE Avtoelektrike.

Praktičen rezultat izvedene toplotne obdelave so (v hladnem preoblikovani) jekleni pastorki s trdoto površine približno *HRc* = 65 in površinsko utrjeno plastjo s trdoto *HV*1 višjo od 551 do globine 0,7 mm.

Na podlagi rezultatov izdelanih ekonomskih študij, podprtih s tehničnimi raziskavami in analizami, so v podjetju instalirali drugo napravo za toplotno obdelavo istega proizvajalca, tipa in enake kapacitete.

Key words: Heat Treatment, Steel Forgings, Pinion, Temperature Measurements, Automotive Industry

Ključne besede: toplotna obdelava, jekleni odkovki, pastorek, meritve temperatur, avtomobilska industrija

INTRODUCTION

In the Slovenian company ISKRA Avtoelektrika they manufacture, with the processes of cold forming, a great number of a different steel forgings (Figure 1) for Slovenian and European automotive industry. The cold formed steel forgings[1] are, during their exploitation, exposed to the both: high mechanical and temperature loads.[2–4]

In the frame of this investigation work, the efficiency and quality of the heat treatment (case hardening)[5–10] of the one of the most typical cold formed steel forgings from ISKRA Avtoelektrika production program – pinion no. 16.920.633 has been analysed. The material of the pinion is 16MnCr5 grade steel (Table 1), produced in Slovenian steelwork Metal Ravne, with well known mechanical and thermal properties.[11]

Table 1. Chemical composition of 16MnCr grade steel in mass fraction, *w*/%

		w/%								
	Element	C	Si	Mn	Cr	Cu	Al	Ni	P	S
Standard [11]		0.14–0.19	<0.40	1.00–1.30	0.80–1.10				<0.035	<0.035
Testing	Analysis 1	0.162	0.241	1.192	1.014	0.049	0.033	0.147	0.013	0.026
Charge	Analysis 2	0.164	0.247	1.167	1.028	0.044	0.035	0.146	0.014	0.027

Figure 1. Cold formed steel forgings from ISKRA Avtoelektrika production program. Testing forging – pinion no. 16.920.633 (below, the second from the left).

Figure 2. Device for heat treatment in ISKRA Avtoelektrika.

A device for heat treatment installed in ISKRA Avtoelektrika (Figure 2) is produced by the company CODERE from Switzerland. It consists of four main parts[12]:

- gas furnace (with pure and high controlled atmosphere),
- primary temperature measuring system (measuring the atmosphere temperature in the furnace),
- manipulating system, and
- hardening vessel (with mineral oil).

Experimental Work

For the purpose of temperature measurements[13] of the testing charge a secondary temperature measuring system (Figure 2) consisting from three basic elements[14] has been designed:

- even coated Ni-NiCr thermocouples,
- data acquisition module ADAM – 4018, and
- personal computer (with Microsoft Excel program) which recorded the results of the measurements.

Figure 3. Positions of the samples in the testing charge.

In the frame of our investigation work five testing forgings were bored. Ends (tips) of thermocouples were inserted therein and fixed with wire. Then, in the filling of the basket with the forgings, the five testing forgings were put on precisely defined, pre-selected places in the basket (A, B, C, D and E). Their positions are shown in Figure 3.

The basket holding the forgings has the form of a cylinder, of dimensions: diameter 780 mm and length 680 mm. The basket can hold approximately 700 forgings, which results in the whole charge mass of some 220 kg, and together with basket approximately 325 kg.

The heat treatment in the case given is case hardening which consists of carburizing and hardening. The prescribed time schedule of the heat treatment process is divided in three phases:

- heating,
- superheating, and
- cooling down (hardening) phase.

The first phase is an even heating of the charge up to the temperature 920 °C (the prescribed time of heating ranges from 2 h to 3 h). The time set for superheating of the charge in the furnace at 920 °C is 3.5 h to 5 h. The cooling down phase (hardening) of the whole charge follows in the mineral oil (OLMAKAL Rapid 90) with the initial temperature 80 °C approximately 10 min.

For the recording of the temperature measurements results a 3 s time interval was selected. The ambient temperature cca 1.5 m from the furnace was measured in the same time intervals on the sixth measuring channel. Complete results of the temperature measurements performed in the heat treatment of the testing charge of the cold formed steel pinions, and detail of the cooling down phase are shown in Figure 4.

The efficiency and quality of the heat treatment was analysed with the use of:

- chemical analysis (Table 1),
- hardness measurements,
- measurements of carbon and sulphur content in the case hardened surface layer, and
- metallographic examination methods.

Surface hardness of the testing samples was measured with the Rockwell (*HRc*) method. All measured values were higher than *HRc* 62 (between *HRc* 62.5 and 67.1).

In the Table 2 are presented the results of the hardness measurements (*HV*1) through the case hardened surface layer (average values of 10 measurements), and in the Table 3 a carbon and in the Table 4 sulphur content in the case hardened surface layer at different distances from the surface (0.1 mm to 1.0 mm).

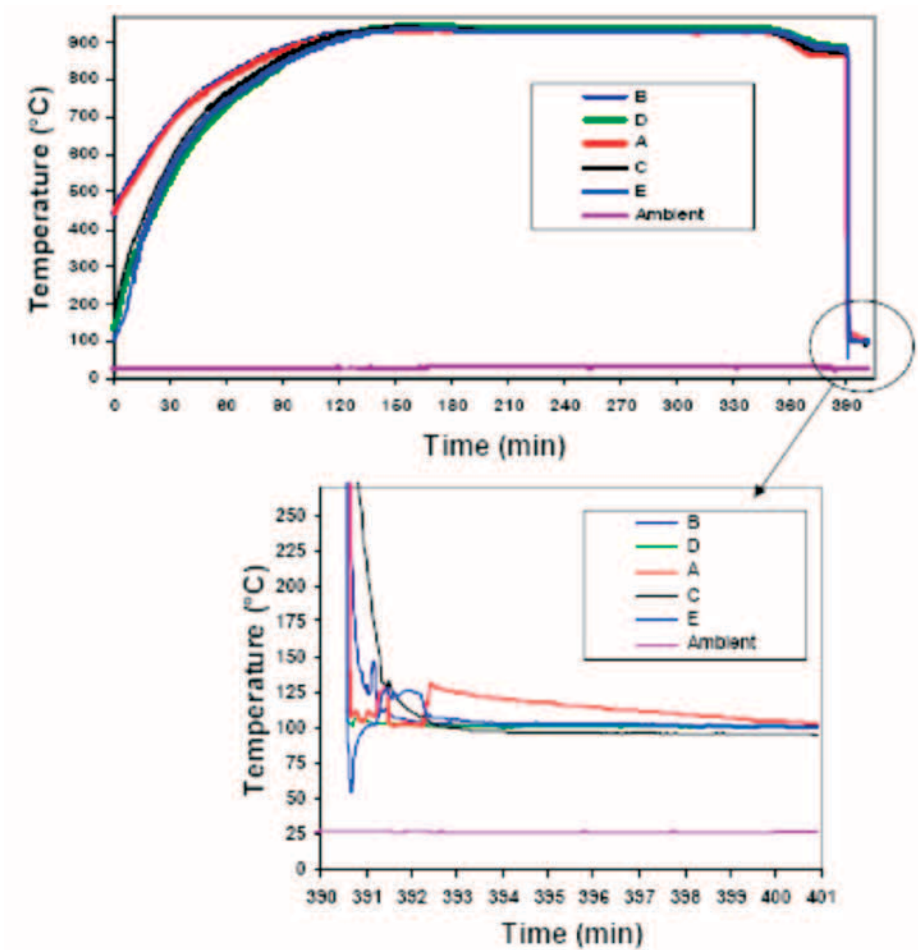

Figure 4. Temperature measurements – testing charge.

Table 2. Hardness through the case hardened surface layer.

Sample	Hardness ($HV1$)									
	0.1 mm	0.2 mm	0.3 mm	0.4 mm	0.5 mm	0.6 mm	0.7 mm	0.8 mm	0.9 mm	1.0 mm
A	854	839	838	800	751	684	615	564	524	491
B	846	847	840	824	749	698	630	578	531	498
C	843	805	784	744	658	647	585	548	523	503
D	824	778	740	696	656	602	565	528	509	497
E	861	860	854	827	786	734	669	613	573	534

Table 3. Carbon content in the case hardened surface layer of the samples A, C and E.

Sample	w/%									
	0.1 mm	0.2 mm	0.3 mm	0.4 mm	0.5 mm	0.6 mm	0.7 mm	0.8 mm	0.9 mm	1.0 mm
A	0.891	0.771	0.745	0.787	0.776	0.744	0.728	0.743	0.724	0.710
C	0.742	0.689	0.658	0.653	0.631	0.569	0.507	0.503	0.448	0.395
E	0.814	0.696	0.683	0.673	0.678	0.599	0.620	0.618	0.630	0.613

Table 4. Sulphur content in the case hardened surface layer of the samples A, C and E.

Sample	w/%									
	0.1 mm	0.2 mm	0.3 mm	0.4 mm	0.5 mm	0.6 mm	0.7 mm	0.8 mm	0.9 mm	1.0 mm
A	0.072	0.032	0.031	0.032	0.030	0.031	0.031	0.030	0.029	0.026
C	0.052	0.035	0.033	0.028	0.028	0.028	0.028	0.029	0.028	0.028
E	0.057	0.029	0.029	0.028	0.027	0.022	0.021	0.028	0.028	0.027

In the frame of our experimental work also non-destructive metallographic examination by optical microscopy (OM) and scanning electron microscopy (SEM) was applied. In the Figure 5 is the microstructure (martensitic) of the surface layer of the tooth, and the crack through the surface layer at the tooth of the sample D. The crack length is approximately 650 μm.

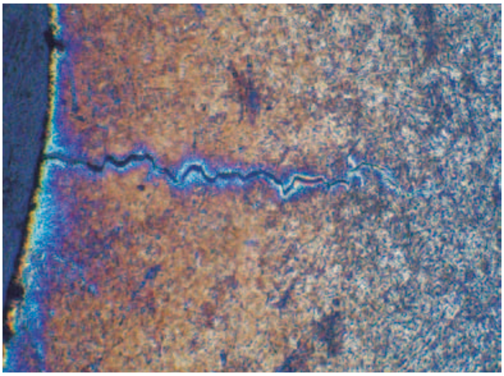

Figure 5. Sample D – tooth. Surface layer, crack through the surface layer; magn. 500-times; OM.

Figure 6. System for heat treatment after installation of the second device.

Conclusions

A gas furnaces and devices play important role in the heat treatments of various metal parts for the automotive industry. Their thermo technical characteristics have a great influence on the both: product quality and costs.

In our case the efficiency and quality of the heat treatment procedure were analysed with the use of: chemical analysis, micro hardness measurements, measurements of the carbon and sulphur content in the surface layer, and metallographic examination methods.

The practical result of the before described heat treatment are cold formed steel pinions with the surface hardness of approximately *HRc* 65, and the case hardened depth of the surface layer (with hardness higher then *HV*1 551) approximately 0.7 mm.

On the basis of the results of economical studies, supported by engineering work, the installation of the second device (Figure 6) - of the same producer, type and capacity - for the heat treatment was done.

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