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Microstructure of carbon steel upon conventional and pulsatory forging*

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Currently used medium carbon steel was processed by conventional forging on a laboratory press and by special pulsatory equipment. The structural homogeneity, phase composition and grain size were evaluated. The finest grain microstructure was obtained by means of special conventional cogging procedure; the mean grain size was less than 5 µm. Pulsatory forging with a different procedure resulted in very fine microstructure, but only in narrow regions of processed specimens. Remaining volume of pulsatory forged specimens consisted of heterogeneous microctructures.

1. INTRODUCTION

The structure refinement of metals and alloys can result in remarkable improvement of mechanical properties [1]. Severe plastic deformation is one of techniques, which promotes the formation of ultrafine grain microstructures. It was established that it is more effective to use multi-pass deformation instead of a single pass deformation. This fact is commonly used in controlled rolling. At present new techniques are sought which make possible to achieve homogeneous ultrafine grain structure not only in metal sheets but also in bulk material [2].

In this article we describe the use of the pulsatory forging for a production of a fine grain microstructure in steel. For this aim special pulsatory equipment was developed by the COMTES FHT company.

2. EXPERIMENTAL PROCEDURES

The experiments were carried out on medium carbon steel 0.42C-0.5Mn-0.25Cr-0.3Ni-0.17Si [wt%]. Austenitization of specimens was performed at 1050^{o}C in an electrical resistance furnace for 60 minutes. Three different forging methods were applied to achieve fine grain homogeneous microstructure:

1. Forging of cylindrical specimens (35 mm diameter and 84 mm length) involved cogging between flat dies and turning by 90^{o} between individual blows. Number of reductions, pauses between the blows and the type of cooling are listed in Table 1. In processing of specimens 3 and 4 additional intercooling down to the temperature of 650^{o}C, reheating at 880^{o}C and repeated cogging were included.

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Table 1
Procedures of conventional forging of the first set of specimens

Specimen	Reduction to the thickness in individual numbered blows [mm]							Pauses between blows [s]	Pause [s]	Type of cooling (reheating)
	1	2	3	4	5	6	7			
1	23	23	23	23	21	21	21	4	6	pressure air
2	23	23	23	23	22	22	22	4	2	oil
3	23	23	23	23	22	22	22	4	225*	reheating 880°C/ 40min/
	22	22	-	-	-	-	-			pressure air
4	23	23	23	23	22	22	22	4	225*	reheating 880°C/ 10min/
	22	22	-	-	-	-	-			pressure air
5	23	23	23	23	18	18	18	4	2	between dies

*….intercooling down to 650°C, reheating and repeated cogging

2. Pulsatory forging of specimens with a diameter of 20 mm and a length of 35 mm was performed using special mechanical pulsatory equipment. Different frequencies, amplitudes and combinations of cogging and upseting were used. Between individual forging procedures reheating at 1150°C was applied. The conditions are described in Table 2. Different forging forces were applied using set of springs with different stiffness.

Table 2
Procedures of pulsatory forging of the second set of specimens

Spec.	1st (2nd) procedure of forging	Frequency [Hz]	3rd procedure of forging	Frequency [Hz]	Cooling
Forging with the first set of springs with lower stiffness.					
P1	upsetting	20 Hz/ 10s	-	-	air
P2	upsetting	25 Hz/ 10s	-	-	air
P3	upsetting	30 Hz/ 10s	-	-	air
P4	upsetting	35 Hz/ 10s	-	-	air
P5	upsetting	40 Hz/ 10s	-	-	air
P6	upsetting	35 Hz/ 10s	-	-	water
P7	cogging	35 Hz/ 10s-1150°C-35 Hz/10s-1150°C	upsetting	35 Hz/	air
P8	cogging	35 Hz/ 10s-1150°C-35 Hz/10s-1150°C	upsetting	35 Hz/	water
Forging with the second set of springs with higher stiffness.					
P9	upsetting	35 Hz/ 10s	-		air
P10	upsetting	35 Hz/ 20s	-		air
P11	cogging	35 Hz/ 10s-1150°C-35 Hz/10s-1150°C	upsetting	35 Hz/	air

3. Comparative conventional forging was applied on specimens of the same initial geometry as specimens processed by pulsatory forging. The same combinations of cogging and upsetting and the total reductions were used in corresponding pulsatory and conventional forging. Amounts of reductions, pauses and reheating between the blows and type of cooling are summarized in Table 3.

Table 3
Procedures of conventional laboratory forging of the third set of specimens – comparative set to pulsatory forging

Spec.	Cogging to the thickness /pause	Reheating/ pause	Cogging to the thickness /pause	Reheating/ pause	Upsetting to the thickness /pause	*Cooling*
C5 C6	- -	- -	- -	- -	20 mm/20s 20 mm/20s	*air* *water*
C7 *C8* *C11*	*13 mm/10s* *13 mm/10s* *13 mm/10s*	*1150^{o}C/300s* *1150^{o}C/300s* *1150^{o}C/300s*	*13 mm/10s* *13 mm/10s* *13 mm/10s*	*1150^{o}C/300s* *1150^{o}C/300s* *1150^{o}C/300s*	*19 mm/10s* *19 mm/10s* *15 mm/10s*	*air* *water* *air*

Each of processed specimens was cut along its longitudinal axis. One half was used for macroscopic evaluation of structural heterogeneity, from the second one metallographic samples were prepared in longitudinal and also in transversal sections. Microstructures were observed in a light microscope (LM) and a scanning electron microscope TESLA BS 340 (SEM). Quantitative microstructural evaluations – grain size and volume fraction of ferrite and pearlite - were carried out using image analysis software Lucia, version 4.6. Structure was revealed by etching in 6% and 3% nital solutions.

3. RESULTS AND DISCUSSION

Different levels of strain and temperatures during forging resulted in a structural heterogeneity of specimens. In longitudinal section of specimens after conventional cogging (specimens 1 - 5) three main parallel bands were observed: the central fine grain band, adjacent lighter bands with even finer microstructure and dark narrow bands near the surface of specimen, where relatively coarse structure occurred (Fig. 1a). Grain size was measured along five horizontal lines in five locations (marked with∗).

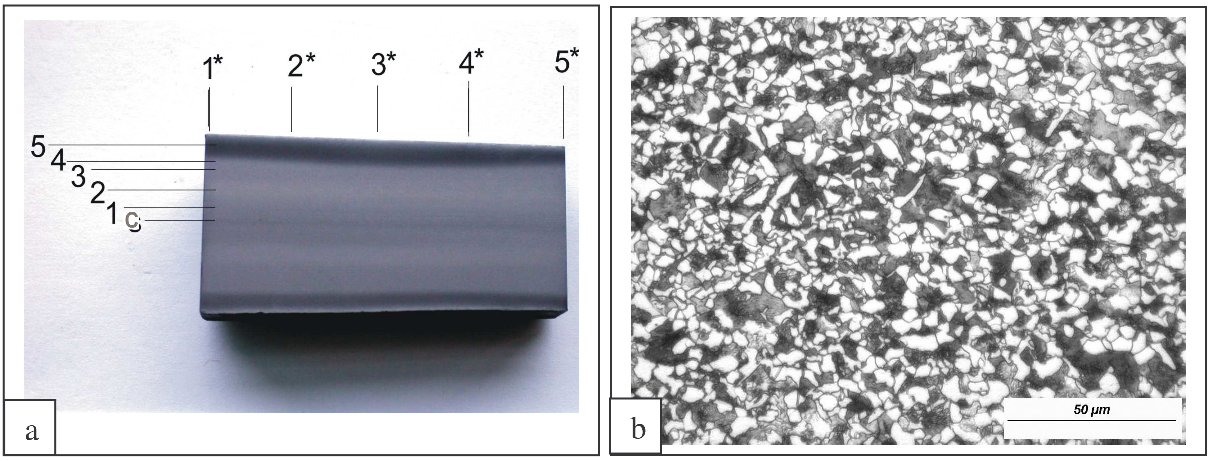

Fig.1. Specimen 3: (a) macrostructure in the longitudinal section, (b) LM micrograph of fine grain microstructure in the central part of specimen

Very fine microstructures were obtained, when intercooling below the transformation temperature A_{r1} was used. Then recrystallization was retarded and final mean grain size of specimens 3 and 4 was 4.6 μm and 5.1 μm, respectively (Fig. 1b). In addition, fine grains of ferrite and pearlite were uniformly distributed in volume of specimens except of narrow surface layers (surface layers were excluded from the mean grain size calculation). The pearlite fraction was almost the same along the vertical lines, about 73 % in the both specimens.

Grain size in steel upon pulsatory and comparable conventional forging was measured in four regions in transversal sections of specimens. The finest microstructures were observed in the central parts of specimens. After pulsatory upsetting (specimens P1 – P6) grain size did not decrease below 12 μm. Distinctive influence of frequency was not found. Remarkable additional refinement was not observed even when repeated cogging and upsetting were applied (specimens P7 and P8); then grain size in the finest regions was 11 μm and microstructure was heterogeneous. In specimens cooled in the air ferrite formed network along the perlite boundaries. Microstructure of water cooled specimens consisted of fine martensitic matrix and small pearlitic nodules (Fig. 2a). Utilisation of higher forging force slightly decreased grain size down to 10 μm. Microstructure of corresponding conventionally forged specimens was coarser but more uniform in the whole specimen volume (Fig. 2b).

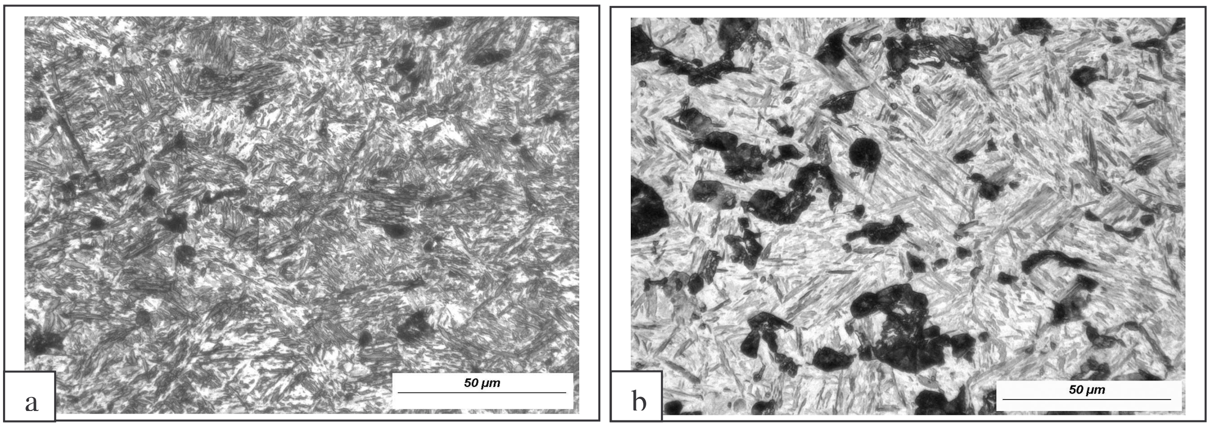

Fig. 2. Comparison of microstructure upon pulsatory and conventional forging. LM micrograph of martensitic pearlitic microstructure in the centre of specimen: (a) P8 and (b) C8

4. CONCLUSIONS

A special conventional forging which results in uniform ferritic pearlitic microstructure with a grain size of 5 μm was developed. Another new technology - pulsatory forging - resulted also in microstructure refinement, although comparably fine grain microstructure was not obtained. In addition remarkable structural heterogeneity was observed. However, pulsatory-forged specimens possessed finer microstructure than specimens processed with comparable conventional procedure.

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