Arch. Metall. Mater., Vol. 61 (2016), No 4, p. 1969–1974

DOI: 10.1515/amm-2016-0318

A. SMALCERZ*,#, J. BARGLIK*, D. KUC*, K. DUCKI*, S. WASIŃSKI*

THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF CYLINDRICAL ELEMENTS FROM STEEL 38Mn6 AFTER CONTINUOUS INDUCTION HEATING

The paper deals with the influence of induction surface hardening on the microstructure and mechanical properties of cylindrical elements made of steel 38Mn6. The first stage was based on computer simulation of the induction hardening process. The second stage - experiments were provided on laboratory stand for induction surface hardening located at the Silesian University of Technology. Microstructure tests were conducted on light and scanning microscopes. The hardness penetration pattern and thickness of hardened layer were marked. It was found that due to properly chosen parameters of the process, the appropriate properties and thickness of hardened layer were achieved.

Keywords: induction heating, computer simulation, induction surface hardening, microstructure.

1. Introduction

The paper presents investigations which were aimed at the assessment of the influence of induction surface heat treatment on the mechanical properties and microstructure of special unalloyed steel 38Mn6 typically used for toughening and surface hardening. This type of steel is used to produce components of wheels and suspension systems. Steel was used to prepare cylindrical samples with diameter of 8 mm.

The influence of induction hardening on the thickness of hardened layer for various parameters of the process was analysed in many papers for instance in [1, 2, 3]. Tests were conducted on the laboratory stand for induction surface hardening located on the Faculty of Materials Engineering and Metallurgy at Silesian University of Technology [4]. The device makes it possible to steer the position of the inductor in respect to the hardened element in three axes. The device has the option to steer the rotational rate and the rotation angle of the chuck and the possibility of the precise choice of the inductor position in respect of the horizontal axis as well as the chance to set the slide movement precisely so that the right placement of the element on the inductor axis is possible. A cylindrical element made of investigated steel was used in the tests. A computer simulation of hardening process for elements made of steel 38Mn6 was conducted in Flux 3D [5] and QT Steel [6] programs making possible to determine electromagnetic and temperature fields distribution, the temperature of austenitization and cooling rate [7]. The influence of the power and current intensity at constant frequency on the efficiency of induction heating was analysed in [8, 9]. On the basis of conducted experiments the correct parameters of the process were chosen in order to achieve the required thickness of the hardened layer. Applied quenchant made it possible to achieve induction heated complex martensite microstructure with required hardness in this layer.

2. Methodology

The scope of tests included:

- computer simulation of hardening by means of Flux 3D and QT Steel programs.
- the choice of parameters and conduction of induction surface hardening for cylindrical elements made of unalloyed steel 38Mn6 for toughening.
- static tension test of samples in initial condition and after induction surface hardening.
- conduction of hardness distribution and marking the thickness of hardened layers.
- microstructure tests on light microscope.
- fractographic tests of the fractures on scanning microscope.

Chemical composition of investigated steel is collected in Table 1.

TABLE 1

Chemical composition of steel 38Mn6, % mass

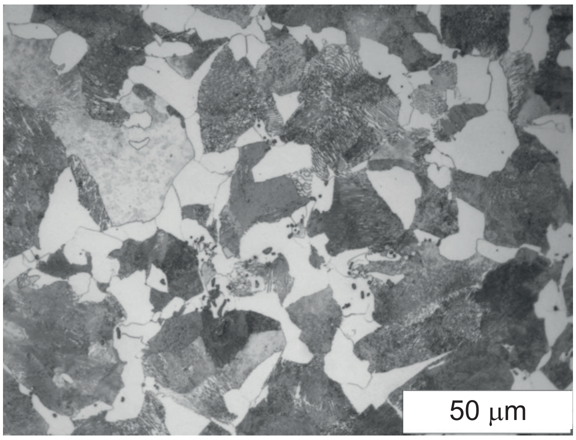
C	Mn	Si	Cr	Mo	Ni	P	S
0.37÷0.42	1.2÷1.6	max.0.25	max. 0.25	max. 0.1	max. 0.15	max. 0.035	max. 0.035

* SILESIAN UNIVERSITY OF TECHNOLOGY, FACULTY OF MATERIALS ENGINEERING AND METALLURGY, 40-019 KATOWICE, 8 KRASIŃSKIEGO STR.POLAND

Corresponding author: albert.smalcerz@polsl.pl

Cylinders from tested steel were in heat refined state and were characterised by pearlitic-ferritic microstructure (Fig.1).

a) Mag. 500×



b) Mag. 1000×

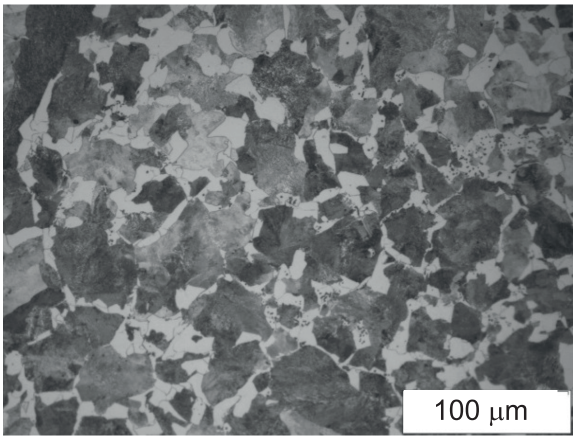


Fig.1. Initial microstructure of steel 38Mn6 in condition after heat refining

Simulation tests were conducted in the program QT Steel which enables prediction of microstructure and properties of carbon steel and alloy steel types in the processes of heat treatment in diversified conditions. View of the laboratory stand is shown in Fig.2.

Fig. 2. Laboratory stand

Laboratory stand for induction hardening has the universal character (Fig.1). It makes possible to treat steel elements with different shapes. The device is equipped with two separate transistor generators of different field current frequencies which makes possible to investigate the dual frequency contour induction surface hardening process of gear wheels. Inductors may be moved jointly along vertical axis with selected velocity. Parameters of the induction surface hardening of cylindrical samples from steel were collected in Tab.2.

TABLE 2

Parameters of induction hardening process of samples

No. of sample	Power [kW]	Movement [mm/s]	Current intensity [A]	Frequency [kHz]
1	8.2	5	825	454
2	9	5	910	454
3	10	6	1005	454

Samples were heated at length of 40 mm and then cooled by means of polymer solution Polyhartenol. Metallographic tests were conducted on light microscope Olympus GX51 with magnification range from 500÷1000×. Hardness tests were conducted with the use of HV1 method. Measurements of hardness from the surface of sample to the axis of sample were conducted for all the samples. Tests of mechanical properties were conducted in the conditions of static test of tension on testing machine ZWICK Roell 100. The observations of sample fractures after tension were conducted with the use of microscope Hitachi S-4200.

3. Modelling the process of hardening

In the first stage, there was a CCT diagram prepared (time – temperature – change) on the basis of average, required chemical composition of steel 38Mn6 (see Tab. 1). Initially, also the chemical composition diagram was also prepared for classic carbon steel type containing 0.3% manganese. The results of the model tests were presented in Figs 3, 4. The addition of manganese significantly broadens the area where martensite appears and decreases the critical cooling time from 2s to about 18s in comparison with the steel types without the manganese addition (Fig. 3). There is also a significant decrease of temperature observed in Ac_3 to a temperature below 800°C. Given temperature for austenitization was 900°C, whereas the cooling curves were corresponding with the conditions of cooling in polymer. It was stated that the steel type is characterised with big hardenability. Cooling with used cooling medium – polymer allows for the achievement of fast rate which exceeds the critical cooling rate for steel 38Mn6 (Fig.4). A martensitic layer can be achieved with a thickness of even 15 mm which provides the required hardness of steel on the level of about 60HRC (630HV).

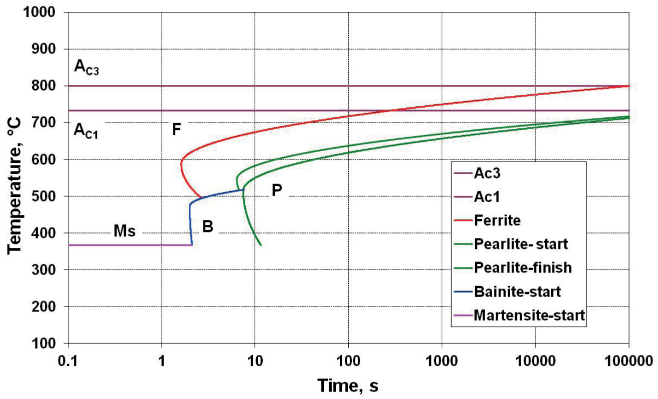


Fig. 3. Model diagram of CCT for carbon steel with 0.3% mass of manganese

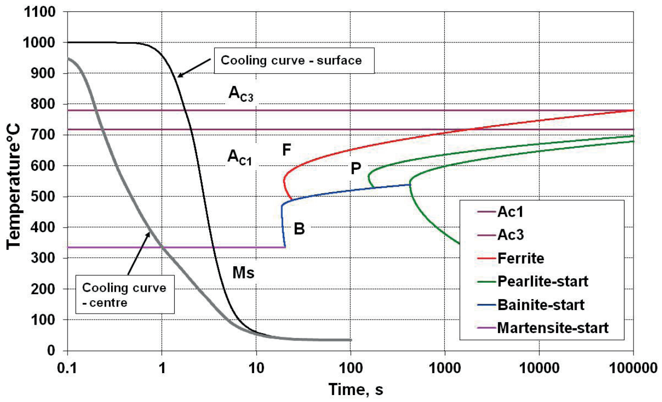


Fig. 4. Model diagram of CCT for steel type 38Mn6 including 1.4 mass % of manganese together with cooling curves

4. Hardness penetration patterns for hardened samples

Changes of hardness on distance from surface for samples after surface hardening is shown in Fig. 5.

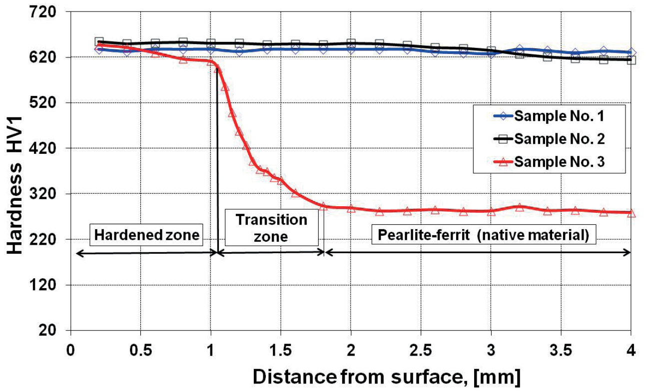


Fig. 5. Changes of hardness in distance from surface of samples of steel 38Mn6 after induction surface hardening

For sample No.1 the uniform hardness distribution in the cross-section is noticed. It equals about 600 - 620 HV without significant differences between surface and the near surface layers. In case of sample No.2, which was hardened with the use of bigger power and current intensity, there were also no changes observed. In case of sample No.3 the power and current intensity was increased one more time together with the current intensity of inductor. The effect of the change in parameters was the achievement of significant difference in hardness between the hardened surface layer and the inner part of the sample.

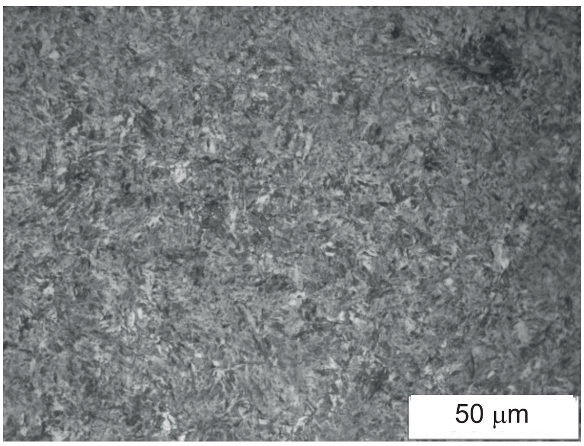


Fig. 6. Microstructure of sample No.1. Martensite structure. Mag. 1000×

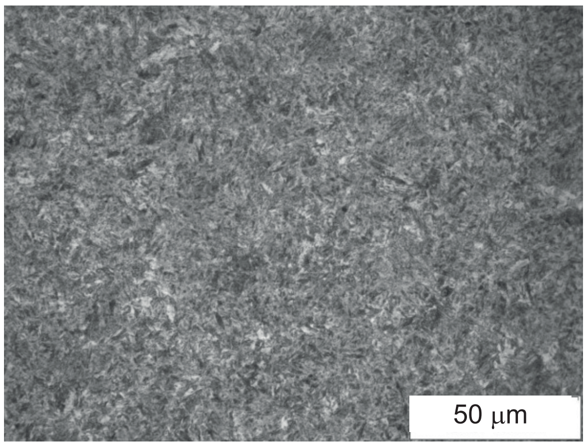


Fig.7. Microstructure of sample No.2. Martensite structure. Mag. 1000×

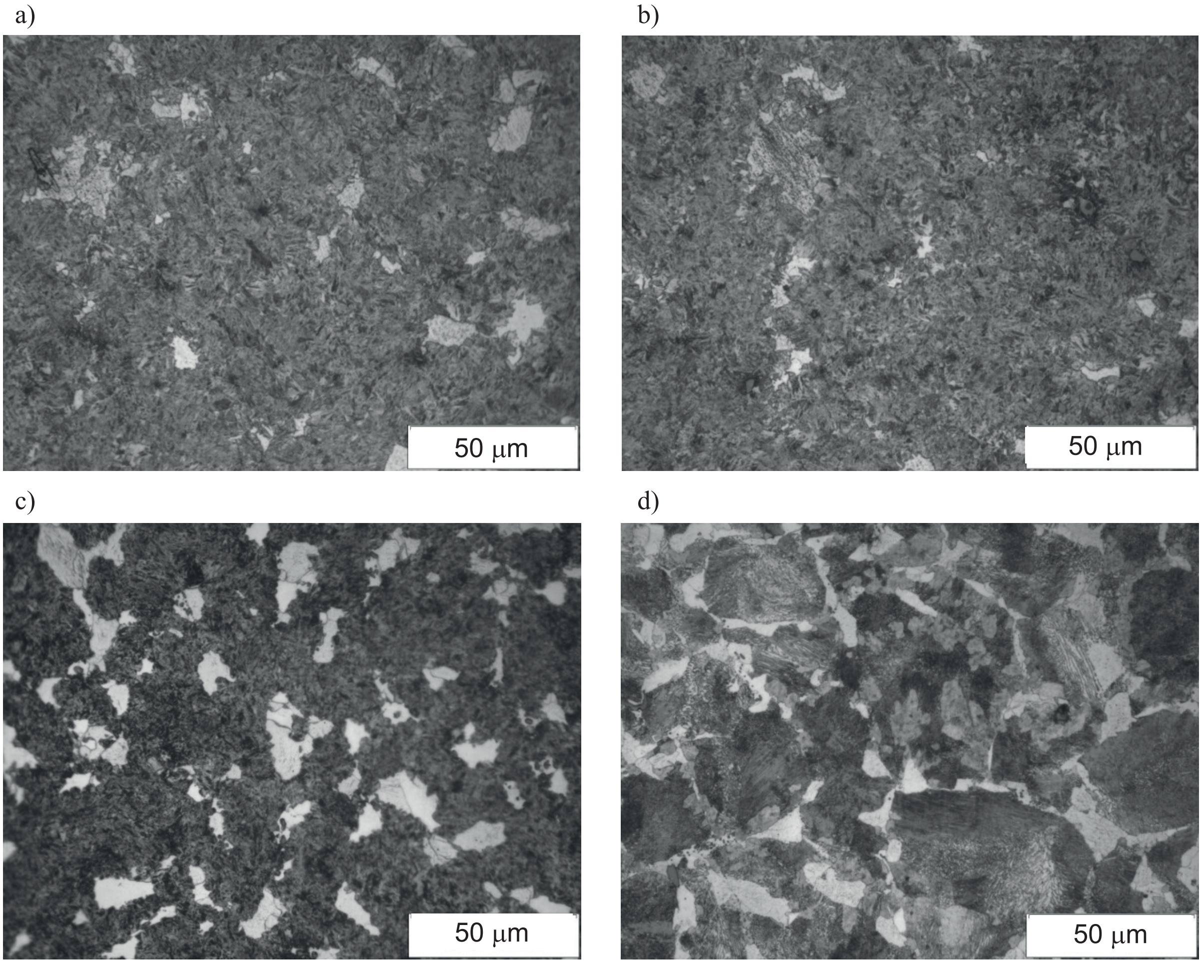


Figure 8. Microstructure of hardened sample with parameters of the option 3 (Tab. 2) on the cross-section in distance from surface: a - 0.2 mm , b - 0.6 mm , c - 1 mm, d - 2 mm. a - martensite microstructure, b - martensite microstructure, c - martensite-bainitic microstructure d- pearlite-ferrite microstructure. Mag. 1000×

The thickness of hardened layer is equal to about 1 mm. The hardness distribution characterized by differences from maximum 620 HV at the surface, 300 HV at the border of the transition zone to minimum of 280 HV in depth of 2 mm inside the material which corresponds with the hardness of steel 30Mn6 in initial condition.

5. Microstructure of samples after surface hardening

The results of microstructure tests after surface hardening are presented in Figs 6÷8. Samples No.1 and 2 show the martensite structure on the whole cross-section area (Fig. 6, 7). The microstructure of sample hardened with parameters according to option 3 on the cross-section in the heated zone, at a distance from surface of 0.2 mm and 0.6 mm was characterised with martensite structure (Fig.8a, b) and 1 mm under surface with martensite-bainitic structure (Fig.8c). The deeper into the material in the non-heated zone the more similar the microstructure was to the initial one in the condition after refining (Fig. 8d).

6. Mechanical properties of steel type 38Mn6 in initial condition and after surface hardening

TABLE 3

Mechanical properties of samples in initial condition and after surface hardening

No.	Yield stress $Rp_{0.2}$ [MPa]	Ultimate tensile strength R_m [MPa]	Elongation A [%]
0	630	860	12.4
1	900	*1035	3.5
2	930	*1050	3.2
3	810	1020	6.8

* - samples cracked before reaching the value of R_m

Results of static tension test of samples in condition after normalisation annealing and hardening are shown in Tab. 3. After normalisation annealing the properties of the tested steel were in the range of requirements included in the standard PN-EN10132-3:2004 (sample 0). Samples which underwent

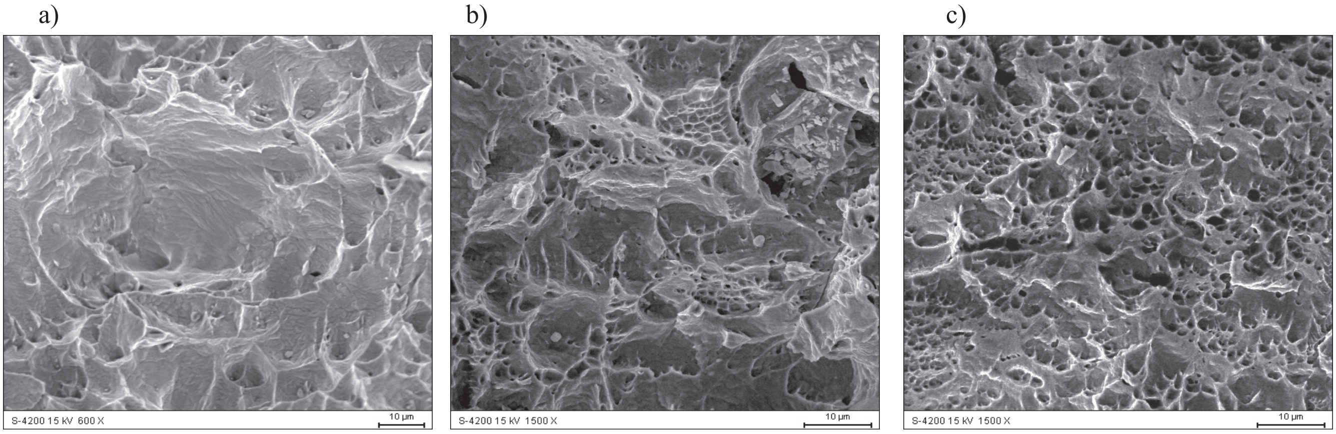


Fig. 9. Fractography of the fractures in sample which was subject to surface hardening - a- hardened zone, b- transition zone, inner zone. Mag. 2000×

hardening cracked right through before reaching a significant value of resistance to tension with small value of elongation (samples 1,2). Steel was surface hardened in the correct way and it has shown about 20% higher strength properties ($R_{p0.2,\ R\mathrm{m})}$ in comparison with samples which underwent normalisation annealing but the plasticity decreased which can be seen in 2×times drop in elongation *A* to failure.

7. Fractography of the fractures of samples after tension

Results of fractographic tests of hardened sample are presented in Fig.9. In the outer zone by the surface the sample possesses feature characteristic for martensitic microstructure which is the transcrystalline fissile fracture (Fig.9a). In transition zone, between the hardened zone and the base material the so-called mixed fracture can be observed where both are brittle and ductile cracking can be seen (Fig.9b). The inner part of the sample has ductile character (Fig.9c).

8. Conclusions

The paper presents influence of induction hardening parameters on the properties and microstructure of cylindrical elements made of steel 38Mn6. Numerical simulation and appropriate practical investigations were provided in order to determine the optimal parameters of surface hardening which would allow to achieve a hardened layer with required thickness (1mm). First tests which differed only in power density and the current intensity led to through hardening of the material. The most important parameter deciding upon obtaining of the requested surface hardened layer was the increase of movement velocity of inductor jointly with increase of power density. For such parameters the heat transmission into the material was limited. Obtained surface hardened layer was confirmed on the basis of marked hardness distribution and microstructure tests. The experience gained in tests will be used to the proper choice of parameters for induction hardening of gear wheels produced for machinery, automobile and aviation industries.

Acknowledgement

The paper was prepared under the Research Project No. PBS2/A5/41/2014, financed by the National Research and Development Centre – Poland.

REFERENCES

[1] V. Rudnev, G. Totten, Induction Heating and Heat Treatment,. 2014 ASM Handbook, Materials Park, Ohio.
[2] S. Zhu, Z. Wang, X Qin, H Mao, K. Gao, J Materials Eng and Performance, **24**, 3919–3932 (2015).
[3] J. Barglik, COMPEL, **35** (4), 1403 – 1417 (2016).
[4] J. Barglik, A. Smalcerz, Comprehensive Materials Finishing, 2017, Elselvier, Oxford.
[5] FLUX3D 10.2 User's guide. Cedrat, Grenoble 2009,
[6] QT Steel - Metallurgical Software for Simulating the Quench and Tempering of Steels, Ita Technology Software, Ostrava Czech Republic (2015)
[7] P. Paszek, Numerical analysis of induction hardening axisymmetric elements, PhD thesis, Silesian University of Technology, Gliwice, 2015, June.
[8] R. Przylucki, S. Golak, B. Oleksiak, L. Blacha, Arch Civ Mech Eng, **11** (1), 171-179 (2011).
[9] J. Lipart, T. Matula, M. Niesler, L. Blacha, J. Filipczyk, Metalurgija, **52** (4), 493-496 (2013).