ANNALS OF FACULTY ENGINEERING HUNEDOARA
– INTERNATIONAL JOURNAL OF ENGINEERING
Tome IX (Year 2011). Extra Fascicule. (ISSN 1584 – 2673)

[1.] Marius ARDELEAN, [2.] Erika ARDELEAN, [3.] Teodor HEPUT, [4.] Ana SOCALICI

ESTABLISHING THE MAIN TECHNOLOGICAL PARAMETERS OF INDUCTION SURFACE HARDENING FOR SHAFT PARTS TYPE

[1-4.] UNIVERSITY POLITEHNICA OF TIMISOARA, FACULTY OF ENGINEERING FROM HUNEDOARA, ROMANIA

ABSTRACT: Induction heating is a particular process which uses electromagnetic fields for heating conductive materials (steel, copper, brass, aluminium). The main difference from a traditional heating process is the location of heat sources which are distributed inside the work-piece. For this reason the induction heating process is very fast and controllable. Depending on the frequency used the heating can be superficial (induction surface hardening) or deep in the piece (forging, heat treatment etc.).
The main advantages of this technology are: high production rate due to the high specific power delivered to the work-piece, high automation of the process, precise repeatability of treated pieces, in-line installation, low floor space needed, controllability of temperature with high precision, avoiding of deformation of pieces especially in surface hardening, primary energy saving, safe and clean work ambient for employees.
There are a lot of applications where induction heating is used in different industries: melting of metals, heat treatments (hardening, tempering, annealing) , forging, hot rolling, surface hardening, cold crucible melting, welding, pre-heating, dry-coating, special applications. All these applications get benefits from the suitable characteristics of this technology.
In this paper is presented the determination of the technological parameters for superficial hardening of axel pieces type made from 41Cr4 and 34CrMo4 steel. This technological parameters is optimum heating temperature, heating time and adequate cooling method for obtains a higher hardness.
KEYWORDS: induction heating, hardness, heating temperature

❖ INTRODUCTION

Surface hardening is a local heat treatment, which is applied to obtain a martensitic structure on the surface of pieces, to the depths between tenths of a millimetres up to 5-10 mm. Surface hardening is done by heating at high speed of the surface layer of products to a temperature in the austenitic range, shortly maintain and rapid cooling at rates higher than the critical quenching speed.

After applying surface hardening results duplex pieces, with hardened outer layer, resistant to wear and fatigue with plastic and tenacious core, resistant to other types of service loads: bending, shock, twisting. In addition, the compressive stress in the hardened layer increases resistance than alternating loads. However, for the combination of features, surface hardening must be applied to semi-hard steel with carbon content between 0.3% and 0.65%.

Given the specific heating conditions, heating temperature decreases rapidly from the surface to the center of product. As a result, only a very thin layer over the surface are heating upper the A_{C3} point and presents after the rapid cooling a complete quenching structure (martensitic), but with different degrees of overheating. Next layer heated between A_{C1} and A_{C3}, becomes an incomplete hardened layer, which makes the transition to the initial structure (feature the core).

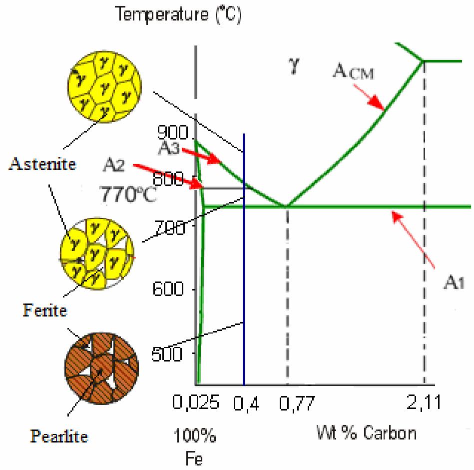

Fig.1. Fe-Fe$_3$C diagram, steel area

The final thickness of hardened layer depends not only completely during heating, but also the time of the finish action of heat source and start cooling, period during which the temperature distribution changes in the product section.

Depth current penetration in the superficial layer and finally hardened layer depth depends on frequency of induced current is determined by the relation:

$$\delta = 5{,}03 \cdot 10^3 \sqrt{\frac{\rho}{\mu \cdot f}}, \ [\text{cm}]$$

where: ρ-receptivity of steel, cm; μ-relative magnetic permeability of steel; f-current frequency, Hz.

For steel the current penetration depth is determined by the formula:

$$\delta = \frac{14,1}{\sqrt{f}}, \text{[cm] at } 15^0\text{C}$$

$$\delta = \frac{200}{\sqrt{f}}, \text{[cm] at } 800^0\text{C}.$$

This change occurs because the magnetic permeability decreases suddenly at reach and overcome the Curie point temperature (770^0 C). In figure 2 is presented some pieces with different hardening depth.

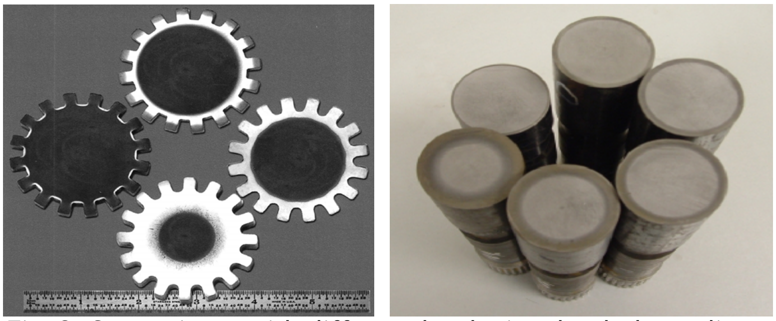

Fig. 2. Some pieces with different hardening depth depending of generator power, frequency and maintained time in inductor

❖ THE STUDY

For practice work of this surface hardening process is requires the following steps: - choosing the power and frequency AC generator;

- ❖ choose the method of heating and cooling;
- ❖ the choice of working parameters.

Special attention is given to steel. The charge is made that preliminary tests, should be possible have the average chemical composition presented in standard and have average hardenability to lower limit of the hardenability band.

Current charge used in the production process must then be reasonably restricted in terms of chemical composition, purity, austenitic grain and hardenability, otherwise there is risk of deviations in treatment results from batch to batch of products.

Of particular importance for the results of inductive quench and subsequent their reproducibility is the initial structure, namely heat treatment earlier surface hardening. Ferito-pearlitic structures (rolling, annealing and normalizing) give a good response to induction surface hardening, with uniform and smooth as possible condition.

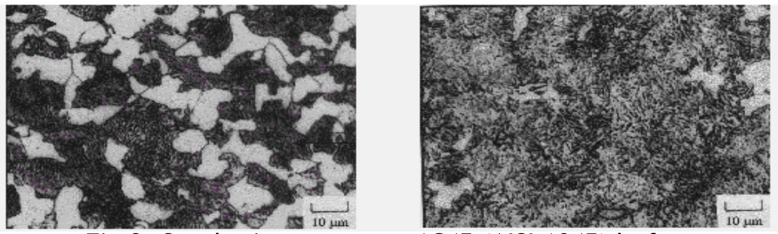

Fig.3. Steel microstructure 1C45 (AISI 1045) before and after the induction surface hardening

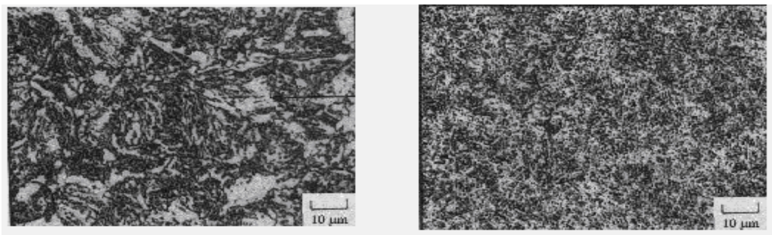

Fig.4. Steel microstructrure 42CrMo4 (AISI 4140) before and after the induction surface hardening

In conclusion, for high frequency current heating, the initial structure of the problem assumes a special importance because it usually is accompanied by an extremely high heating rate and, accordingly, change phase and diffusion processes are limited here within extremely small. The greater dispersion of steel structural components, the solid solution is formed faster and faster the diffusion process completes, which contributes to the uniformity of composition. In figure 3 and 4 is presented a microstructure of steel pieces before and after the induction surface hardening.

It appears that the induction heating is desirable that the initial structure to be sorbite or perlite, where results the different quench depths:

- ❖ steel microstructure dependent mostly on temperature and speed of induction heating, the higher the heating rate is higher, the layer structure of hardened steel will be fine;
- ❖ it is desirable that the initial structure of steel is therefore required to provide good properties for core, i.e. resistance;
- ❖ initial structure should favours changes in solid state and there lead to a favourable state and to eliminate the soft layer (ferrite network and transition layer).

A surface hardening equipment, fig.5 is composed of high-frequency generator and tempering machine, whose construction depends on the geometry of surface hardening of parts subject. Also in this picture is presented work principle for induction heating.

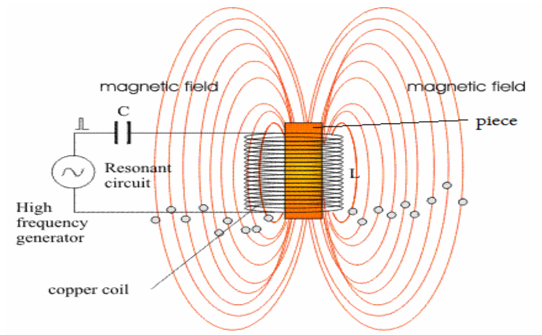

Fig.5 Work principle for induction heating

❖ DISCUSSIONS

Experiments were conducted in the laboratories of the Faculty of Engineering Hunedoara. For experiments have been used a specialized facility for surface induction hardening (type CTC100K15 compact frequency converter), T200 FLIR thermal imager, a radiation pyrometer ST88 PLUS and a metallographic microscope type Krüss Optronic. Medium frequency power converter converts the medium frequency power used of induction heating. All parts of converter, both as external power is cooled with water. It is recommended for reducing the cost of cooling water, the water recirculation and cooling in a heat exchanger.

Power circuit of converter is a parallel resonant LC circuit provided with of inductive and capacitive compensation composed from inductor and hot work pieces. Power circuit includes tempering transformer, shown in the figure below, and also is presented the inductor who are used in experiments.

Quenching transformer is shown in figure 6, is provided with multiple entries, depending on the inductor used. If heating is not correct (too long heating time) is needed to move to other transformer connections tempering (Φ30 mm inductor, transformer coupled 4:1; piece Φ19mm diameter).

For a better control of temperature as was preferred measurements of temperature using thermographic cameras that allows real-time continuous measurement of pieces temperature in inductor with sufficiently high precision. The following figure shows how the pieces temperature was measured.

For experiments we used two sets pieces, consisting of 4 pieces made of steel 41Cr4 improvement, and 6 pieces of steel made from 34CrMo4. The specimens have dimensions Φ19 mm diameter, length 26 m

In order to conduct experiments, it was measured the sample temperature maintained in the inductor, while the power generator was kept constant at 60% and 70% of rated generator power. Please note that attempts to measure temperature and using a radiation pyrometer, but measurement errors occurred because of how the piece is heated (inside the ring inductor with multiple coil). All the pieces were quenched in water, and the hardness was measured in several points on the surface.

Fig.6. Tempering transformer and inductor

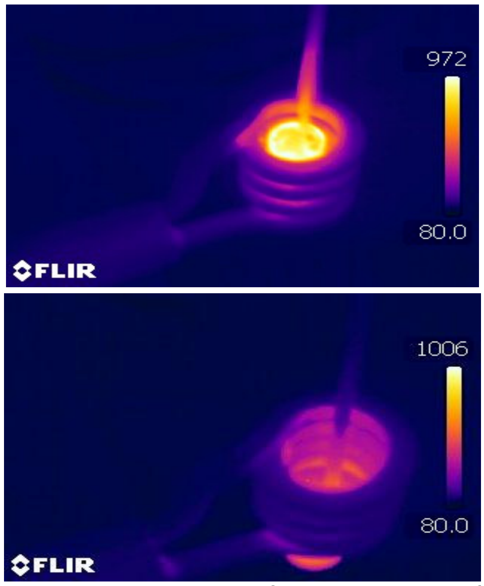

Fig. 7. Temperature of pieces measured with thermographic cameras

❖ CONCLUSION

Since the experiments were conducted using the methodology described above, were measured hardness at three points on the surface of samples by Rockwell method, and the values obtained are presented in the following tables.

Tab.1 Hardness for pieces from 34CrMo4 steel

Pieces	Temperature	Hardness			Time	Power
	^0C	HRC	HRC	HRC	s	%
1	910	52,5	50	52	9,1	70
2	920	53	55	50	11,3	60
3	880	49	46	48,5	10,2	60
4	1002	54	55	51	10,5	70
5	*980*	*57*	*54*	*54*	*9,2*	*70*
6	930	49,5	50	50	11,5	60

Tab.2 Hardness for piceses from 41Cr4 steel

Pieces	Temperature	Hardness			Time	Power
	^0C	HRC	HRC	HRC	s	%
1	840	53	54	47	9,8	60
2	1010	*65*	*61*	*61,5*	*10,7*	*70*
3	972	59	60,5	65	9,1	70
4	980	56,5	59	60,5	12,3	60

In the first phase, a macroscopic analysis of surface was studied of the two cut samples in order to reveal the penetration depth of the hardened layer. These samples are presented in the following figures on the right is highlighted hardened layer, for 41Cr4 steel.

Fig. 8 Microstructure for pieces made from 41Cr4 steel

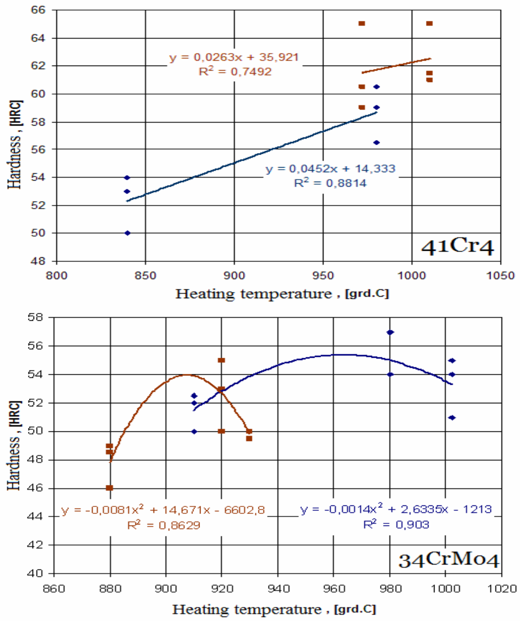

Fig.10. Hardness variation for pieces in case of 60% and 70% nominal power of generator

Hardened layer depth, is about 4 mm for specimens of steel and approximately 3.5 mm for specimens of steel. Are normal differences between hardened layer depth and hardness differences because steel 41Cr4 steel has a greater hardenability as 34CrMo4 steel (higher carbon content and boron contains increases hardenability).

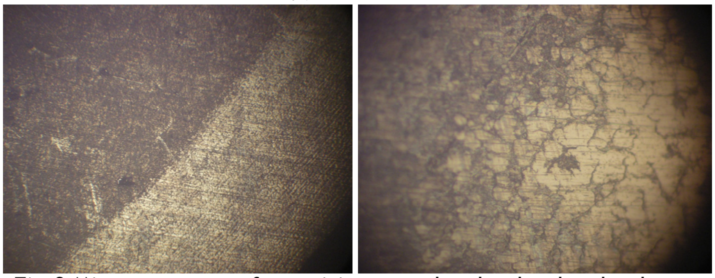

Fig.9 Microstructure of transition zone hardned-unhardned at magnitude 140x - left and 350x - right, for 41Cr4 steel

The sample thus prepared was studied with metallographic microscope, as shown in the following figures some of the photos microstructures obtained. It just shows the microstructure of the steel sample 41Cr4 with different orders of magnitude. In figure 10 and 11 is presented dependences between hardness of pieces and heating temperature for booth of steel quality.

In the case of 34CrMo4 steel data (which are in greater number) can be traced and a spatial dependence, in this case the hardness depending on temperature and time heating. This kind of variance of hardness is built in the statistical analysis program.

In figure 11 is added also the contour graph which provide more suggestive of dependence that exists between the three parameters.

Thus, studying the previous charts are recommended for heating the steel 41Cr4 temperature range 950…1000^{0}C to obtain a hardness of about 58… 62 HRC, while the equipment is above to 60-70% of maximum power (9 ... 10.5 kW).

For steel 34CrMo4, we recommend heating at 940 ... 980^{0}C to obtain hardness values of 52...56 HRC, under the same power condition. In addition, in this case it may recommend duration of heating time to be 9.8 ... 10.6 seconds.

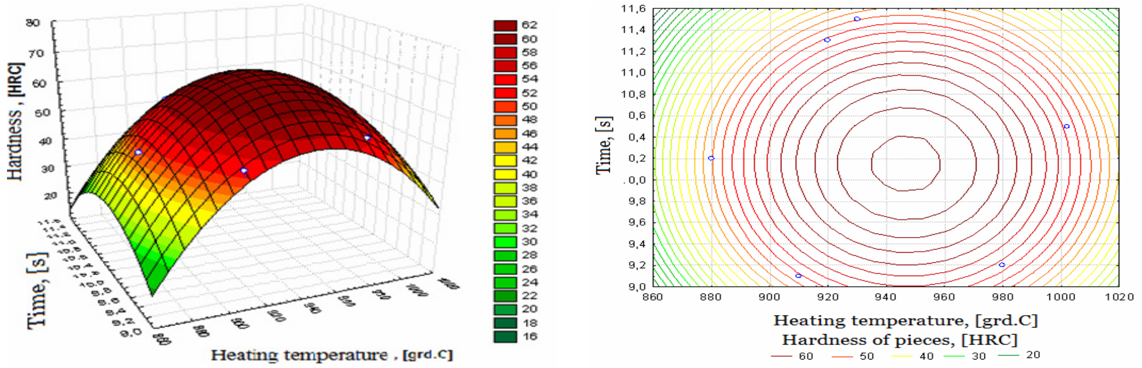

Fig.11. Hardness variation for pieces made from 34CrMo4 steel, cumulative value

In both cases it is noted that the heating temperature for quenching is recommended to be much higher, with 120 ... 150^{0}C than classical austenitic temperature (which for these two steels is 840 ... 860^{0}C), due to this high-speed heating.

❖ REFERENCES

[1.] Carţis I. Gh., - Tratamente termice, Editura Facla, Timişoara, 1982.
[2.] Ardelean M., Prejban I., Mihut G. - Tratamente termice, calcule tehnologice, Editura Cermi, Iaşi, 2007.
[3.] Anghel F. - Metode şi procedee tehnologice, volumul II - Tehnologii moderne, Editura Printech, Bucuresti 2006.
[4.] *** Documentaţie tehnică instalaţie compactă de încălzire prin inducţie tip CTC 100K15, AAGES Targu Mures.