Advances in Science and Technology Research Journal
Volume 11, Iss. 1, March 2017, pages 253–258
DOI: 10.12913/22998624/67676

Research Article

LOW PRESSURE CARBURIZING IN A LARGE-CHAMBER DEVICE FOR HIGH-PERFORMANCE AND PRECISION THERMAL TREATMENT OF PARTS OF MECHANICAL GEAR

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Received: 2016.12.15
Accepted: 2017.02.01
Published: 2017.03.01

ABSTRACT

This paper presents the findings of research of a short-pulse low pressure carburizing technology developed for a new large-chamber furnace for high-performance and precision thermal treatment of parts of mechanical gear. Sections of the article discuss the novel constructions of the device in which parts being carburized flow in a stream, as well as the low-pressure carburizing experiment. The method has been found to yield uniform, even and repeatable carburized layers on typical gear used in automotive industry.

Keywords: heat treatment, vacuum carburizing, lean manufacturing.

INTRODUCTION

The aim of the modern technology of case hardening is to obtain repeatable, precisely planned parameters of a hardened layer, and to minimise the negative processes which bring about dimension changes following quenching, as well as to identify the nature and size of such changes [1, 2]. Low-pressure carburizing followed by quenching is one of the methods by which this can be accomplished, but – along with a number of advantages – it has some weaknesses, which decrease its potential.

Although new technologies have been developed and implemented, there is one feature that has remained unchanged and common to these and the traditional technology: namely, that items are arranged on special equipment to form batches and they undergo the whole case hardening process in this configuration. This means that each item in a batch is affected by the process conditions in a manner unique to a given position, reaching parameters specific to the heating rate, composition of the process atmosphere and rate and direction of cooling. There is no doubt that items in outer layers of a batch are heated more quickly and that they reach a different temperature (according to the temperature distribution within a batch), the atmosphere around them is "richer" and they are quenched more intensely compared to the items within. This results in considerable dispersion of the results of a case hardening process in items inside the batch, e.g.: surface and core hardness, microstructure, and especially the effective case depth [3].

Basically, all the weaknesses and limitations of traditional thermal treatment can be attributed to its batch-related nature. Therefore, to open new perspectives, this factor should be eliminated and replaced with its opposite, i.e. a single-piece flow model. The single-piece flow concept in thermal treatment for mass production has been present in theoretical considerations, industry articles, lectures and presentations for some time [4, 5]. Various system solutions, more or less in line with the idea, have been developed, but no device for mass thermal treatment has been constructed so far that would embody the idea fully. Single-piece flow case hardening should be understood as the process in which every single item goes through identical positions and process conditions, like every item before and after it.

An analysis of the construction solutions applied so far in devices for thermal treatment of steel items has resulted in a new approach to the issue, which has not been described in the literature or proposed by any manufacturer of thermal treatment equipment in the world and which employs a furnace of a special construction (Fig. 1) [6, 7]. The new solution contains three parallel, connected technological chambers in which single items move in a stream; such chambers are arranged horizontally and placed in a common vacuum space with a gas leak-tight separation. The unloading lock is integrated with an individual gas cooling device in the furnace operation cycle, which can be easily connected further to an external tempering device. Therefore, each item passing through the process chambers with stabilised parameters will stay in identical process conditions [8, 9].

The experiment conducted for this study included preparation of a device for vacuum operation and work was launched aimed at developing and implementation in the device of a brand new technology of short-pulse low-pressure carburizing, which would be optimal for this special furnace construction. The ability of the device to carry out short-pulse vacuum carburizing followed by high pressure gas quenching was examined; subsequently, uniformity, evenness and repeatability of the hardened case obtained was tested.

The device resulting from the experiment will be a fully robotised part of a production line which can be included in a system of automatic control of a production process.

MATERIALS AND METHODS

The concept of short-pulse low-pressure carburizing is derived from the *FineCarb* low-pressure carburizing technology, which has been properly documented in the literature [10–16]. The process in the *FineCarb* method is divided into a sequence of pairs of "*boost-diffusion*" segments. Items stay in a chamber with carboniferous gas during several-minute boost segments. The carboniferous gas is evacuated and items are held in technical vacuum during several-minute diffusion segments. There is only one pair of boost-diffusion segments in the short-pulse method, and the duration of both segments is the same. Carboniferous gas in injected repeatedly in short impulses, lasting a few seconds each.

Thirteen processes of short-pulse vacuum carburizing were conducted during the first phase of the experiment by the short-pulse method at temperatures ranging from 950 to 1050°C and with duration of the diffusion segment of 900 to

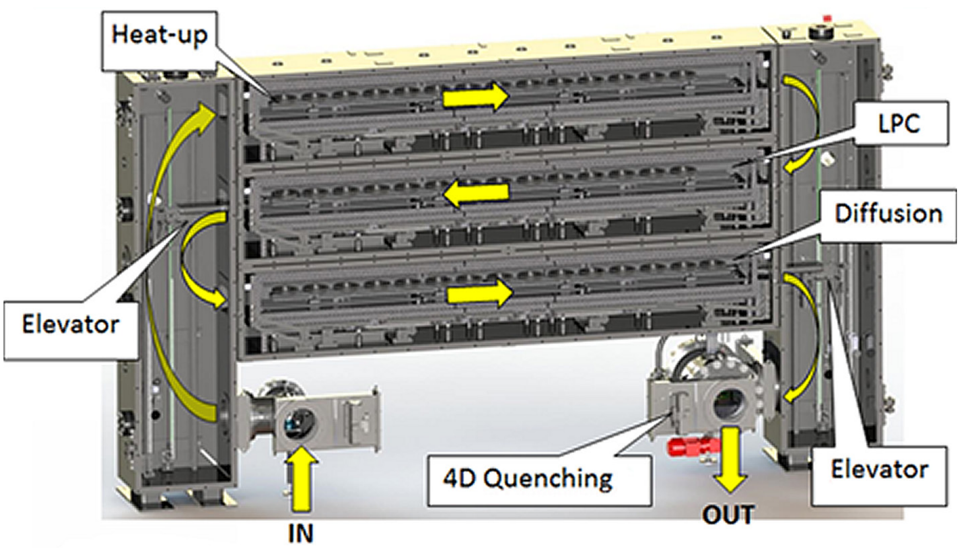

Fig. 1. The vacuum furnace for single-pieceflow case hardening

1200s and duration of carburizing gas injection of 5–30 s with a batch of gears with the diameter of 105 mm, made of EN 20MnCr5 steel. After carburizing, the gears were quenched in gas and tempered in a separate device. Two wheels were treated in each process. They were subsequently taken for carbon and metallographic tests; the following were tested: surface hardness, tooth microhardness profile, hardness profiles at measurement points and carbon concentration profile. The aim of these preliminary tests was to demonstrate the operational readiness of the prototype, including carrying out the process of short-pulse low-pressure carburizing and high-pressure gas quenching. The results of the experiment have confirmed the operational capability and have confirmed that it is justifiable to pass on to the principal tests of quality, evenness and repeatability of the carburized layers.

The main experiment involved low-pressure carburizing at a temperature of 1000°C, the carboniferous gas pressure of (C_2H_2) of 3 hPa and the flow rate of 7.5 L/min on a batch of 25 gears with the diameter of 105 mm, made of EN 20MnCr5 steel. The gears were subsequently quenched in nitrogen at a pressure of 0.5 MPa for 35 seconds. Seven gears were sampled randomly from the entire batch and 4 fragments were cut out of each (at points corresponding to 3, 6, 9, 12 o'clock); the following tests were carried out: measurement of surface hardness, teeth microhardness profile, teeth microstructure, carbon concentration profile.

Table 1. Tests of surface hardness of gears following thermo-chemical treatment

Surface hardness [HRC]					
Gear no	„Hour”				Average
	3	6	9	12	
22	60.6	61.6	61.3	60.2	60.9
25	62.6	62.2	63.8	63.1	62.9
27	63.2	63.7	63.3	62.4	63.2
28	62.5	63.0	62.8	62.5	62.7
29	61.3	61.4	60.1	60.2	60.8
30	61.4	64.2	64.1	62.3	63.0
31	61.7	62.4	63.3	63.4	62.7
34	64.0	63.0	63.2	63.6	63.5
35	62.7	64.2	63.4	62.8	63.3
36	59.6	63.1	61.1	60.2	61.0
37	61.9	63.3	63.6	63.1	63.0
38	63.1	64.4	63.7	62.3	63.4
39	61.7	61.6	61.5	60.9	61.4
41	61.7	62.0	62.0	62.9	62.2
45	63.2	62.2	62.5	62.5	62.6
47	62.7	61.9	63.1	63.2	62.7
48	62.3	61.9	63.3	63.4	62.7
49	59.9	60.1	60.7	59.6	60.1
50	62.1	63.3	61.1	61.2	61.9
52	60.4	60.9	59.9	62.6	61.0
53	62.8	63.7	64.2	63.5	63.6
54	62.5	62.7	64.4	63.0	63.2
55	61.1	62.0	60.9	60.4	61.1
56	62.4	63.2	63.4	63.0	63.0
57	62.4	62.8	62.6	62.0	62.5

RESULTS

The surface hardness tests were performed for all samples. The average surface hardness of the gears was 62.3±1.0 HRC. Detailed results are shown in (Table 1). A distribution of hardness profiles on the gears is shown in (Fig. 2). The profiles for all the gears measured coincided.

The microstructure of the teeth, examined on the addendum, dedendum and flank of the teeth, is shown in (Fig. 3 a-c). The carburized layers were found to be carburized uniformly and their microstructure was evaluated as correct for this process.

The results of concentration measurements in the hardened layers for three selected gears are shown in (Fig. 4–6). Carbon profiles measured at 3, 6, 9 and 12 o'clock points were found to coincide in all the gears taken for the test.

DISCUSSION

The microstructure tests have shown that the layers are uniform and even. Moreover, layer uniformity is also confirmed by the carbon concentration profiles in the layers. Moreover, it was demonstrated in the testing of the bilateral hypothesis that there were no grounds for claiming that the average surface hardness deviates from the nominal value (62.3 HRC). This means that the surface hardness obtained in this experiment is repeatable.

These are the findings of a process carried out at the temperature of 1000°C, at the time of one gear passing through the carburizing chamber of t = 15 min., the carboniferous gas

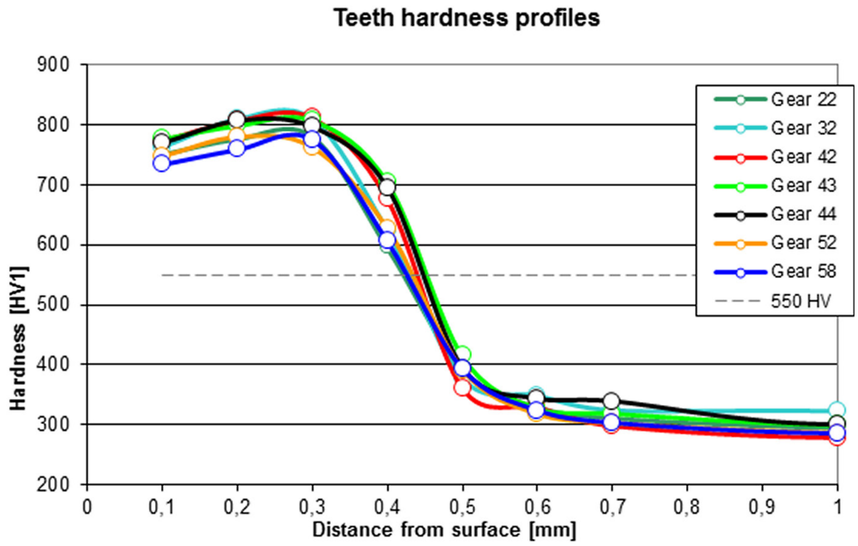

Fig. 2. Hardness profiles measured on gear teeth following treatment

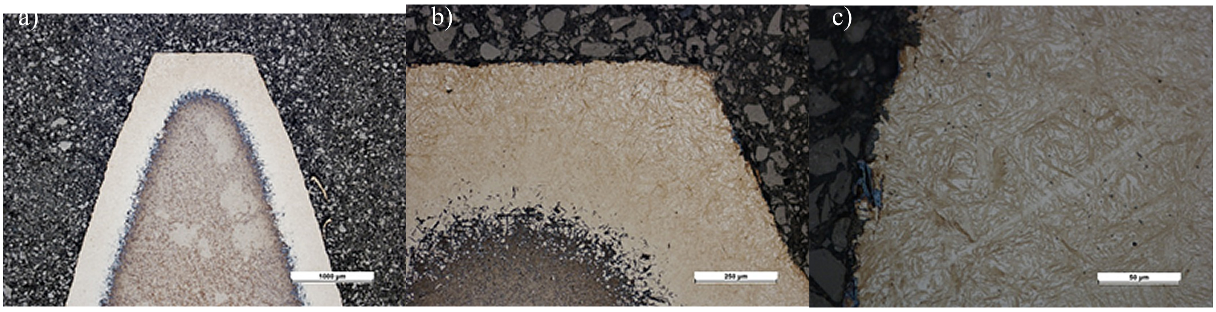

Fig. 3. Tooth microstructures following thermo-chemical treatment; a) gear 22, tooth, magnification x25; b) Gear 22, tooth corner, magnification x100; c) Gear 22, flank, magnification x500

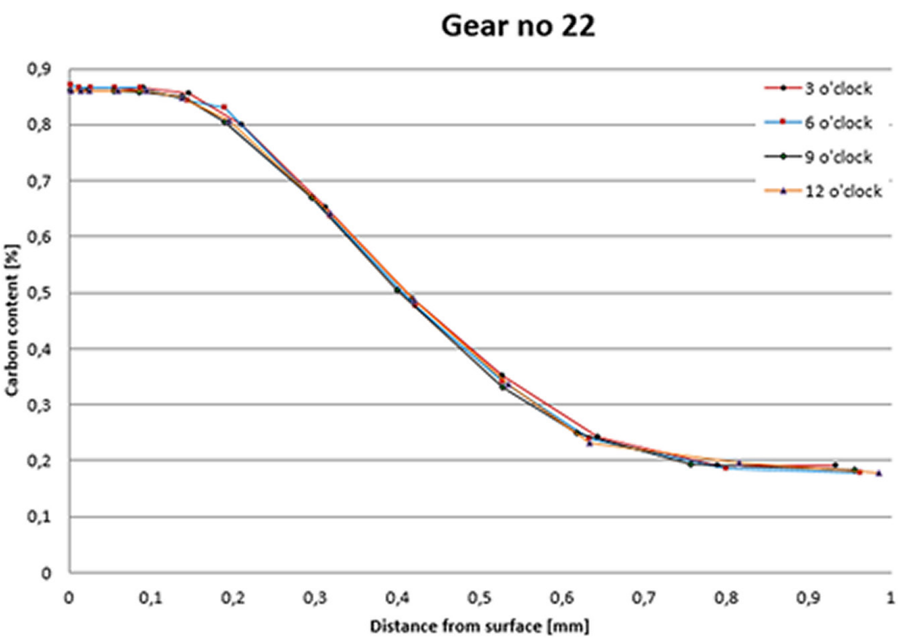

Fig. 4. Profile of carbon concentration distribution in the surface layer in gear no. 22 following carburizing (temp. 1000°C)

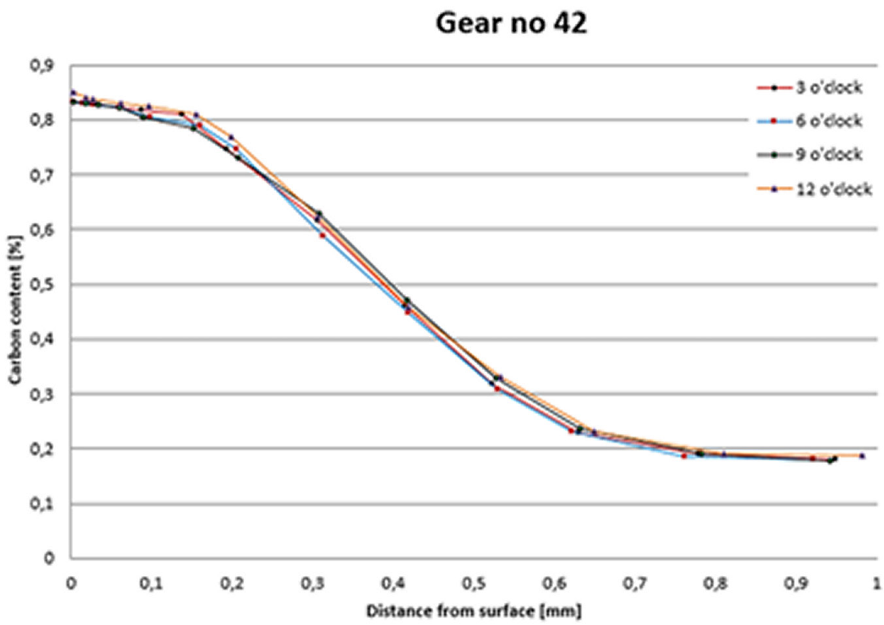

Fig. 5. Profile of carbon concentration distribution in the surface layer in gear no. 32 following carburizing (temp. 1000°C)

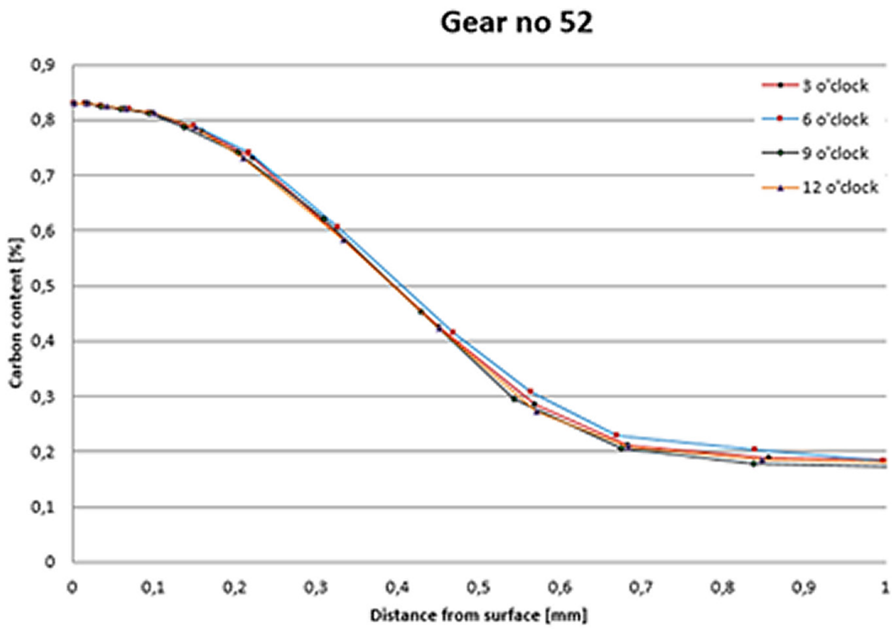

Fig. 6. Profile of carbon concentration distribution in the surface layer in gear no. 42 following carburizing (temp. 1000°C)

(acetylene) pressure of 3 hPa and its flow rate of 7.5 L/min. Currently there are not enough data to determine whether it is the optimum (minimum sufficient) pressure and passing time for this process temperature and this batch size. It is advisable to carry out more studies in order to determine the optimum combinations of acetylene pressure and flow rate as a function of temperature, time and the batch surface area.

CONCLUSIONS

1. The device ability to carry out the process of short-pulse vacuum carburizing followed by high pressure gas quenching has been confirmed.
2. Uniformity and evenness of the hardened layers obtained by the treatment has been confirmed for the whole item surface.
3. Hardness of gears achieved in the process has been found to be repeatable.

Acknowledgments

The research and publication were financed by the National Centre for Research and Development as part of project no. POIR.04.01.04-00-0087/15 entitled: “Equipment for high performance and precise heat treatment with a quenching deformation reduction system for direct application in downstream production chains of mechanical gearing and bearings”.

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