

**SYNTHESIS REPORT  
FOR PUBLICATION**

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# Synthesis report

## Plasma Carburizing with High Pressure Gas Quenching

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## 2. SUMMARY

### 2.1 Keywords

Plasma Carburizing  
 Gas Quenching  
 Steel hardening  
 Heat treatment

### 2.2 Abstract

The main aim of the project was to install a plasma carburizing process into a conventional vacuum heat treatment plant with high pressure gas quenching of nitrogen up to 10 bar and helium for carburized steel parts. To reach higher quenching velocities the furnace was equipped with hydrogen quenching. The combination of the two processes, plasma carburizing and high pressure gas quenching in one chamber promised a lot of advantages.

A furnace chamber was designed, build and installed, equipped with the plasma carburizing process and the gas quenching. Plasmagenerator, interface and electrical control as well as the safety installations, the gas supply and gas outlet were developed and installed respecting the requirements for the use of hydrogen at high pressures. Investigations of model- and industrial steel parts revealed the relationship of carburizing depth and the plasma parameters as well as quenching gas, gas pressure and heat transfer coefficients in the newly build system.

Results showed that quenching rates as high as those achieved by oil can be obtained. With these quenching rates the gas quenching process is no longer limited to high alloyed steels. The merits of the new process can be fully exploited by the European heat treatment industry keeping their competitive edge. Main advantages are:

- Avoiding oil waste
- Less energy consumption
- Reduction of production time
- Less dimensional alterations and distortions

These advantages have to be seen in relationship to considerable higher costs for the use of hydrogen as quenching gas and higher investment costs for the vacuum heat treatment furnace with high pressure gas quenching.

### **3. THE CONSORTIUM**

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### 3.2 Consortium description

The consortium of this project is horizontally structured as it consists of four heat treatment shops (**VHP, Junge, STC, Rübige**) and vertically structured as it consists of the component manufacturer (Plasma Generator by **Plateg**) the system producer (**ALD**) and the endusers, the heat treatment shops.

The endusers in this project, the heat treatment shops **VHP in Hamburg, Junge in Herzberg, Rübige** in Wels (Austria) and **STC** in Sint Truiden (Belgium) differentiate their activities by heat treatment processes, client sectors and geographic areas. Their main role in this project was the definition of their demands concerning gas quenching processes and installations. Intensive discussions with their clients and the collection of sample parts from them assured always a steering of the project closely related to industrial needs

The system manufacturer **ALD** has designed and build the new **furnace**. **Plateg** has **modified** their plasma generator for the plasma **carburizing** process to fit into the new **furnace** and to interface with the control system.

The **R&D** performer in this project is the **Stiftung Institut für Werkstofftechnik (IWT)** in **Bremen**. This Institute comprises of more than 45 years of experience in the treatment of surfaces not only by heat treatment. Intensive know how is **also** available on techniques for **carburizing** and **nitriding** as well as the Institute is equipped with most modern in house analytical systems.

The project management and administrative coordination was carried out by **AXON Technologies Consult GmbH**, a consulting firm specialized in the initiation and management of regional, national and international technology transfer projects.

## 4. TECHNICAL ACHIEVEMENTS

### 4.1 Introduction

The main aim of the project was to **install a** plasma **carburizing** process into a conventional heat treatment plant with high pressure gas quenching. To **fulfil the** demands set to quenching intensity by conventional **carburized** steels it was planned to equip the **furnace** with a 20 bar hydrogen quenching **tool**. The combination of these two processes promises a lot of advantages.

**Plasma-assisted** heat treatment for the **carburization** of metal surfaces was a laboratory method when the project was started. It is still a just rarely employed technique today. Heat treatment shops are expected to use this new technology in the near **future**. While there exist **already** well-working simulation tool for **gas-carburizing** processes, there are so **far** only little information on how to adjust the many **different** process

parameters in a **plasma carburizing** process. But compared to the usual gas **carburizing** processes it offers considerable economic and environmental advantages:

- . No negative influence on **surface** by internal oxidation
- . Postprocesses machining and cleaning can be minimised
- Ten times less gas consumption
- Higher energy efficiency

## 4.2 Instrumentation and results

Usually, **carburized** steel parts are quenched in oils with high quenching velocities. In combination with the **plasma carburizing** process oil-quenching can only be **installed** in an expensive two-chamber **furnace**. The so far used high pressure gas quenching tools cooling velocities are too low to be applied on most of the **carburized** steels. To increase the quenching velocities in the **furnace** in this project hydrogen is used, the gas with the best cooling **behaviour**, with pressures up to 20 bar. The first results showed that quenching rates as high as those achieved. by oil can be obtained. **With** these quenching rates the gas quenching process is no **longer** limited to” high **alloyed** steels, and the merits of the new process can be fully exploited:

- Avoiding oil waste
- Less energy consumption
- . Reduction of production time
- . . Less dimensional alterations and distortions

### 4.2.1 The vacuum furnace

Until now, only helium is used for this pressures. The **usage** of hydrogen is limited to lower pressures by safety regulations. To be allowed to use hydrogen in a heat treatment plant a lot of demands by the **German** technical surveillance society (TÜV) had to be **fulfilled**. The. result of the- **engineering** work. on the plant is shown in figure 1.

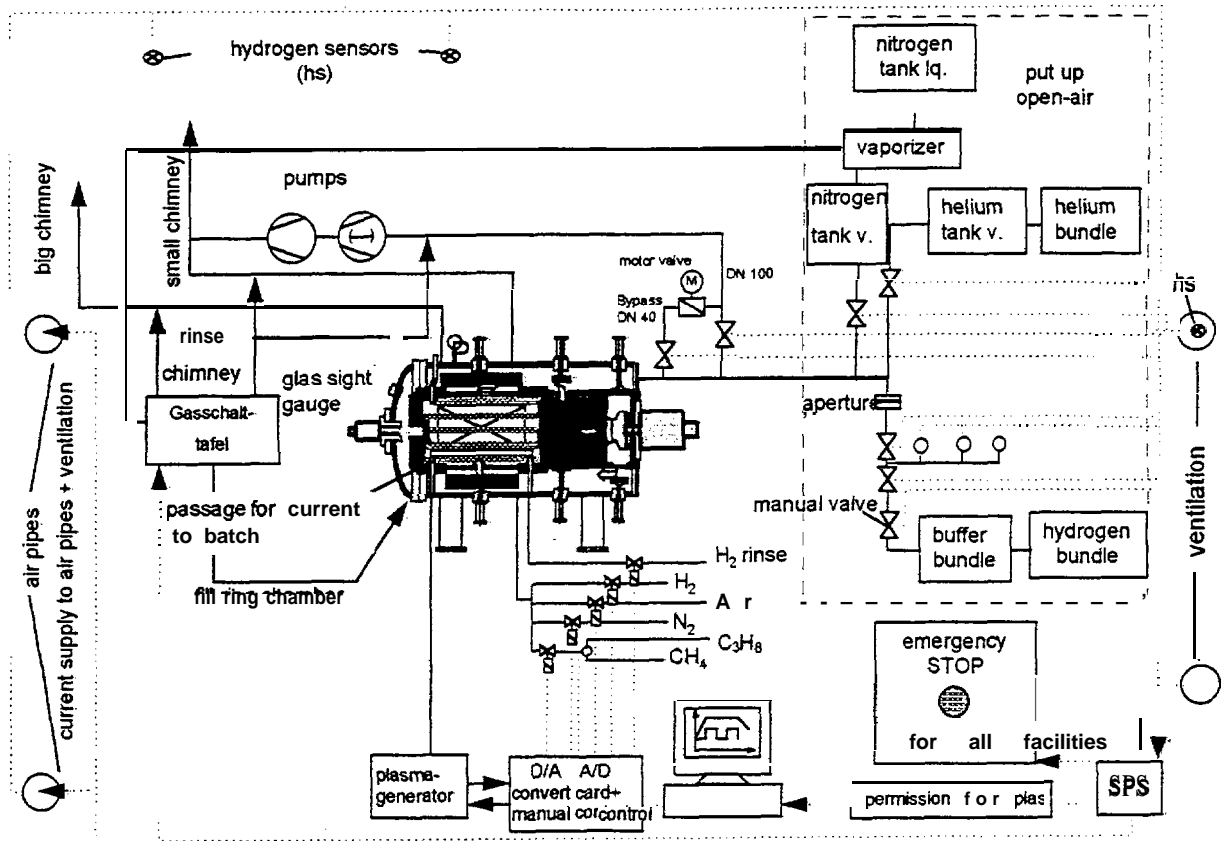


Fig. 1: Schematic description of the modifications done at the vacuum heat treatment plant

#### 4.2.2. Examination of carburized steel hardening

First of all the hardening behaviour of carburized steels was examined in a quenching vessel. The vessel has a volume of 561 and is designed to operate with pressures up to 21. bar. The heating, up, of the sample occurs inductively to prevent a heating up of the surrounding components. The sample, except for one end surface, is protected by a ceramical tube from quenching. The gas flow occurs through a replaceable centred nozzle on the end of the sample and leaves the vessel at the bottom. The vessel was developed to characterise the gas quenching conditions in-general for different alloys by a gas jet of varying known velocities in a chamber with regulated varying pressures. In this facility hardenability of different alloys was examined in dependence on the used gas, the pressure and the gas velocity. The cylinders were metallographically examined on the quenched side. The Hardness was measured in several distances below surface and the hardening depth (distance in which a hardness of 550 HV is reached) determined. In figure 2. the connection between hardening depth, the gas and the pressure is shown as an example of the results.

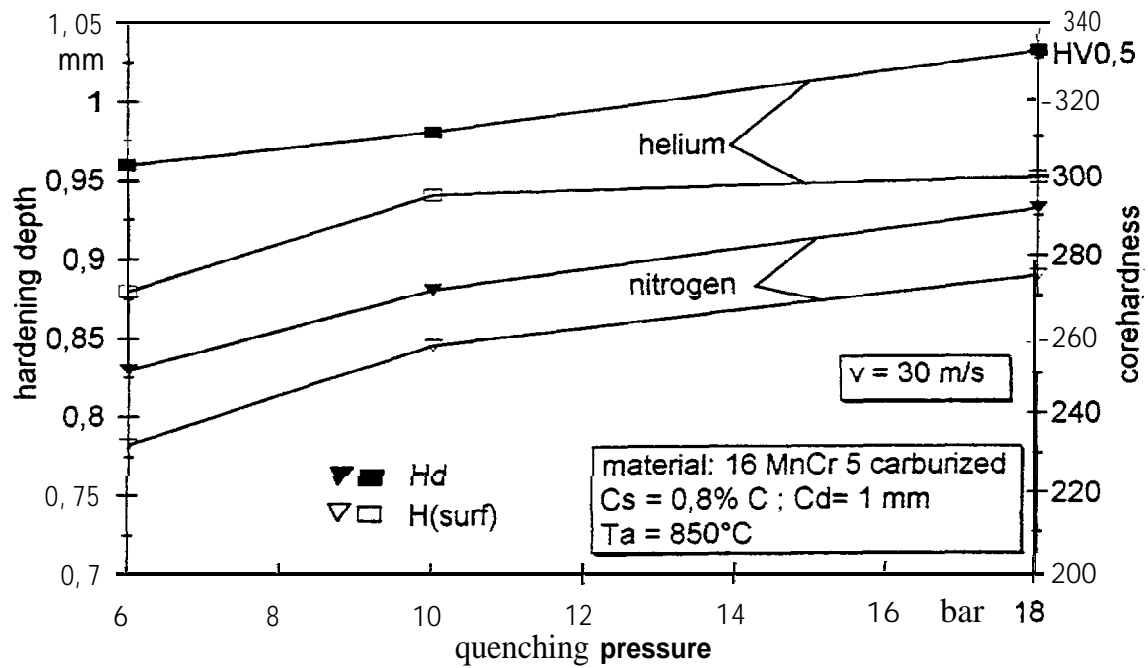


Figure 2: Connection between carburizing depth, gas and gas pressure

The figure shows that the hardening depth is higher with helium than with nitrogen. It is the same for the core hardness. However, helium is much more expensive than nitrogen, so that from an economic point of view the advantage of helium is declined. On the other hand hydrogen is even more effective than helium and not much more expensive than nitrogen. The hardening depth and the core hardness rise with the pressure of the process gas. But it is a rise on a descending scale.

#### 4.2.3 Investigation of carburizing depth, gas and gas nature

In the second part of the experiments gas carburized cylinders with diameters of 8, 18, and 28 mm were quenched with high pressure gas quenching in the described vacuum heat treatment furnace. After the quenching process the hardening depth and the hardness on the surface of the parts were determined. These trials were carried out for three different positions in the heating chamber, with several pressures, different main flow directions and different alloys. In the batches the temperature curves are measured in special austenitic samples. With these temperature curves it is possible to calculate the heat transfer coefficients.

In figure 3 the connection between type of gas, pressure and the heat transfer coefficient in the used heat treatment plant is shown as an example for the trials carried out in the plant.



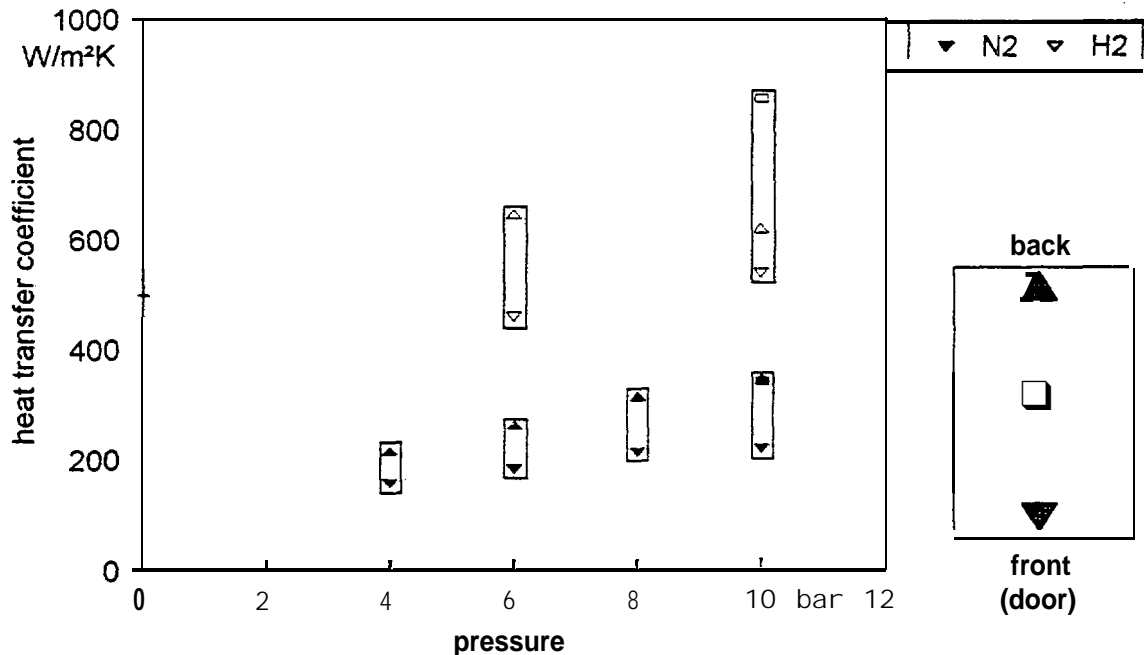


Figure 3: Variation of the heat transfer coefficient with pressure for hydrogen and nitrogen

The figure shows that there is a more powerful heat transfer with hydrogen than with nitrogen. The heat transfer rises with the gas pressure, but it is a rise on a descending scale. The differences between the heat transfer coefficient in the front and in the back of the heat chamber are bigger with hydrogen than with nitrogen in these trials. The differences in heat transfer coefficient are dependent on the batch density. There arises more turbulence in a batch with a higher density and with this the evenness rises.

#### 4.2.4 Transferability of results

In the third part it was tried to translate the knowledge on plasma carburizing on the new furnace. A result of this task was, that there is only little transferability for working processes: from one plant to another. It was inevitable to do the main informing trials again. Figure 4 shows the results of the informing trials. The trials are a mixture of different processes with varying parameters (e.g. process gas pressure, mass flow of process gas, area of the batch, carburizing time,...). Figure 4 shows that it is possible to reduce these varying influences on an influence through the current density and the process gas per area,

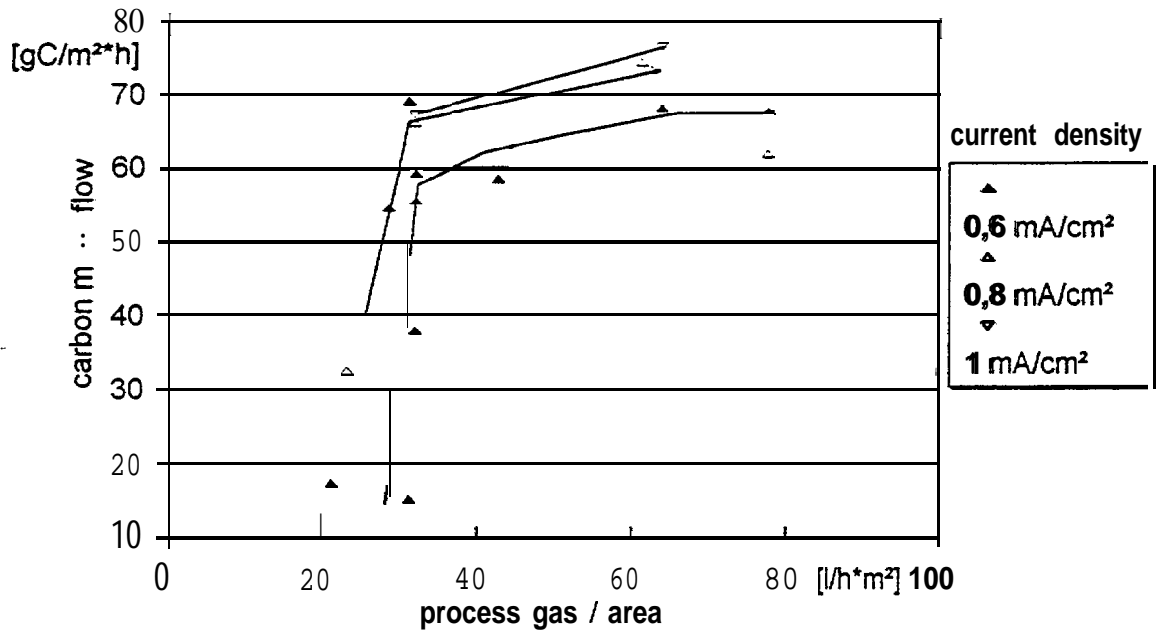


Figure 4: Variation of the carbon mass flow into the surface of 16MnCr5 samples with the process gas / area for different current densities

It can be derived from the figure, that for this plant it is useful to work with a process gas mass flow of 80 l/h\*m<sup>2</sup> to receive results to calculate with.

#### 4.2.5 Experiments on industrial parts

In the last and most important part of the experiments, industrial parts, chosen by the partners in this project; were carburized and gas quenched in the new heat treatment plant. The results were compared to the same parts, carburized and quenched in a conventional way at the heat treatment shops. An example is shown in figure 5. A batch of 51 I parts (ea. 60x40mm) were quenched with 20 bar hydrogen. The figure shows the evenness of the quenching result. It is possible to see, that the evenness in the front part of the oven is better than in the rear part. On the left hand side, the reached hardness is higher than on the right side and in the rear part higher than in the front part. One of the main advantages of gas quenching is the high reproducibility. By changing bits of the structure of the batch this unevenness can be equalised. If the perfect batch structure is known it can be used again and again.

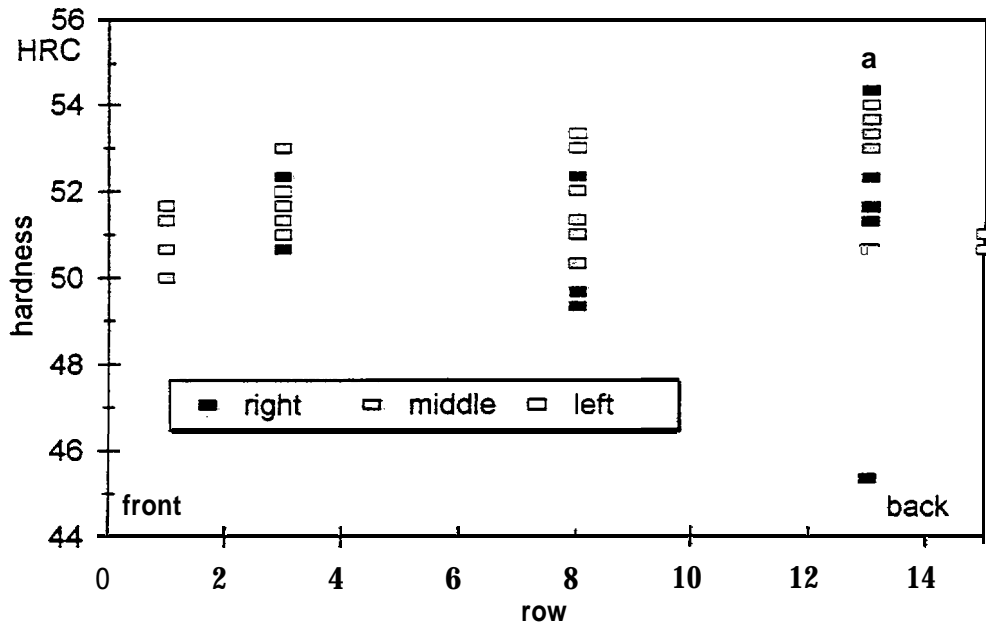


Figure 5: Hardness results of a batch of 511 industrial parts (5 layers, 15 rows)

## 5. Exploitation plans and follow-up actions

The exploitation of the project results will be twofold. The heat treatment shops will exploit the project results by offering the new processes to their customers and the component and system manufacturers will exploit them, by the production of systems applying the new processes.

The heat treatment shops have gained experience and know how on the plasma carburizing and gas quenching processes. They have analyzed the demands of their customers and can decide on the implementation of the newly developed technology. The project provided results for model and industrial parts which serve as references in the discussions with new clients. As all manufacturers of metal parts which need to be hardened are operating in a very price-sensitive market but are nevertheless obliged to keep up with the safety and environmental regulations in their countries and at their locations an alternative to conventional oil quenching can be offered now.

The components and system manufacturers have gained in depth experience on the needs of heat treatment shops and respectively their clients in respect to plasma carburizing and gas quenching. Experiments in the new system revealed strengths and weaknesses of the new processes which will lead to improvements of the future products. The approval of the safety concept for the plant by the relevant German authorities has led to considerable changes which can be introduced into new products and the plant itself can serve as demonstration for interested customers.

In general it is expected that increasing environmental standards in the approval procedures of industrial installations and even in the **further** operation of plants located in living areas will increase the demand for environmentally **friendly** processes. Additionally the costs for the treatment of waste oil are expected to increase tremendously in the **future** making the new processes more interesting and competitive. The manufacturers of the new systems expect to sell five installations in Europe over the next three years. This **will lead** to return for the investments made within this **R&D** project.

The **R&D performer will** publish the results of this project **after** receiving permission by the partners.

It is planned to participate in the next **Härtereikolloquium** in October 1997 in **Wiesbaden** and show results to the heat treatment community.

## **6. References**

In 1995 a Television Spot was recorded by the broadcasting station **Deutsche Welle**. Within the science and technology magazine Leonardo this spot was broadcasted as one example for **impacts** of European **R&D** grants on Small and Medium enterprises.

## **7. Collaboration sought**

There is no collaboration sought.