Heat Treatment of Stainless Steels Using the SolNit® Process

Ipsen USA
Cherry Valley, Illinois

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Abstract

SolNit is a heat-treatment process similar to case hardening, but it uses nitrogen instead of carbon as an alloying element. The industrial process SolNit uses vacuum furnaces with high-pressure gas quenching for nitriding stainless steels. There are two versions of the SolNit process: SolNit-M for martensitic and SolNit-A for austenitic stainless steels. These processes allow low-grade stainless steel to be hardened and used in everything from surgical tools to household appliances.

Compared to standard case hardening, the SolNit process has several advantages for stainless steel:

- Increases surface hardness without decreasing corrosion resistance properties
- Eliminates the generation of metal carbides in steel
- Increases resistance against wear, erosion, and cavitation
- Improves high-temperature strength
- Is environmentally friendly and safe through its use of nitrogen as a process gas

Introduction

The solution nitriding, process SolNit was developed by Ipsen in the late 1990s, in cooperation with Hîrterei Gerster AG, Switzerland. This partnership resulted in the development of two robust industrial process for hardening stainless steels - SolNit-M and SolNit-A.

- **SolNit-M** (for martensitic steels) improves the surface hardness and associated properties, while retaining a relatively ductile core and increasing corrosion resistance.
- **SolNit-A** (for austenitic steels) creates high compressive stress in the surface zone of a component, which results in increased cavitation resistance.

The SolNit processes allow low-grade stainless steels to be used in applications that extend from the typical markets for stainless steels (chemical and medical industries, as well as kitchen and household appliances) to fields where special magnetic, electrical, low-temperature and surface properties are of prime importance.

Basics of Process Technology

Typically, carburizing and nitriding high-alloyed stainless steels within the temperature range of 932 °F to 1832 °F (500 °C to 1000 °C) is not possible due to a loss of corrosion resistance. The low solubility of these steels leads to the formation of chromium carbides and chromium nitrides, respectively, which reduces corrosion resistance.

A carburizing treatment at temperatures between 1472 °F and 2102 °F (800 °C and 1150 °C) favors the formation of carbides $Cr_{23}C_6$ and Cr_7C_3, respectively, whereas a nitriding treatment between 896 °F and 1652 °F (480 °C and 900 °C) results in the formation of nitrides CrN and Cr_2N.

One way to avoid the formation of chromium carbides and chromium nitrides is to reduce the carburizing or austenitizing temperature to values at which no precipitations are formed during the treatment time; this is the case at temperatures between 662 °F and 752 °F (350 °C and 400 °C). Unfortunately, low-temperature processes only produce thin surface layers of approximately 10-30 µm.

The formation of thicker diffusion layers was made possible by the development of the SolNit process. The procedure is based on the knowledge that with higher contents of chromium, manganese and molybdenum, the nitrogen solubility of the steel at temperatures above 1922 °F (1050 °C) is increased [1].

Figure 1 shows the differences between the usual limits of chromium content in stainless steels and the regime of homogeneous austenite in nitrogen-alloyed steel showing that it is wider and extends to a higher interstitial portion than in the case of carbon-alloyed steel.

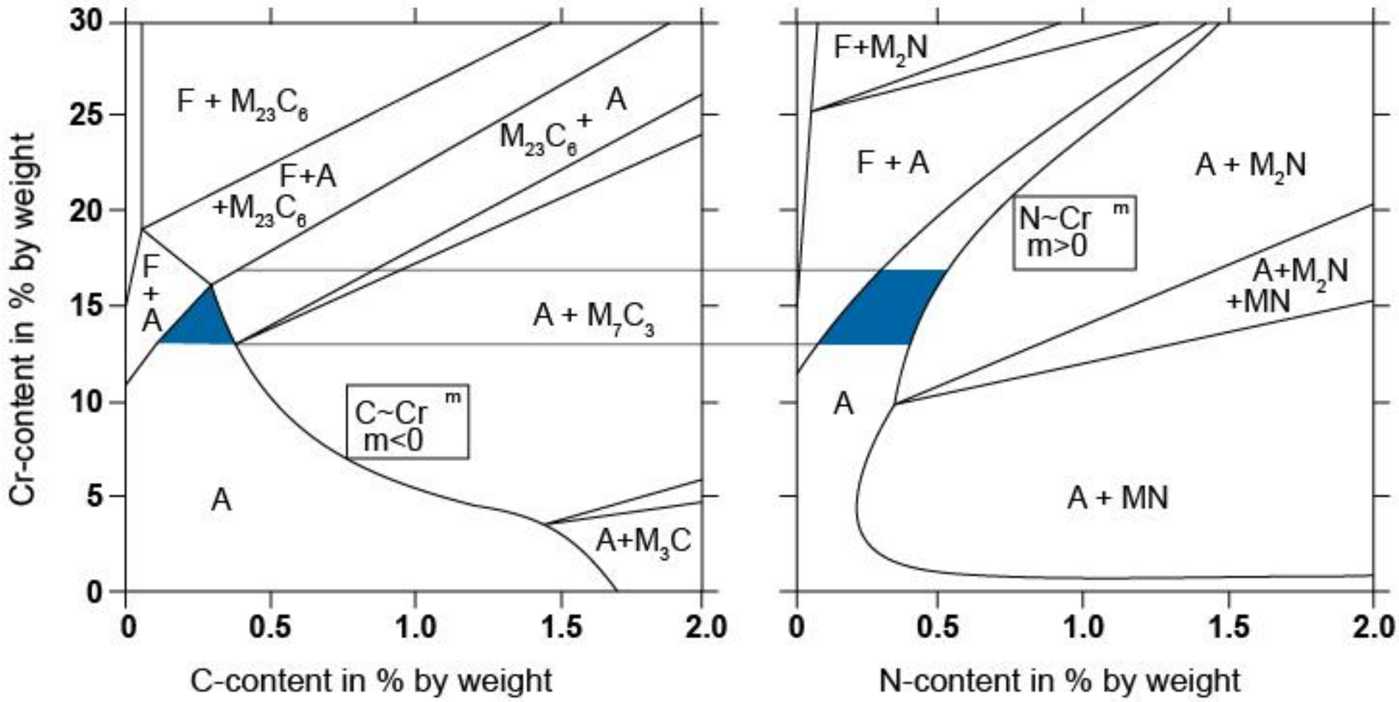

Figure 1: *Isothermal sections of equilibrium phase diagrams at 2012 °F (1100 °C). Within the common limits of Cr in stainless steel, the regime of homogeneous austenite is wider and extends to a higher interstitial content in the nitrogen-grade steel compared to the carbon-grade steel*

Process Version: Martensitic Case

The martensitic process version creates a hard case combined with a tough core. The solved nitrogen improves the corrosion resistance in media containing acid and chloride. The hardness values of the case are in the range of 58 HRC to 60 HRC combined with compressive stress.

Process Version: Austenitic Case

The austenitic process version creates a corrosion-resistant case with high nitrogen content, strength and ductility. In aggressive media, these properties provide resistance against surface fatigue. An additional mechanical solidification of the surface (e.g., shot-blasting) leads to compressive stresses and improves fatigue strength.

The resistance against cavitation is also strongly increased by this process, which creates an aggressive media that can be used for application in fluid-flow machines, such as pumps, turbines and the associated armatures.

Process Technology

The SolNit process technology is relatively simple, when considering that all-metal surfaces have two-atomic nitrogen molecules, which dissociate into atomic nitrogen at temperatures above 1922 °F (1050 °C). In spite of the passive surface of stainless steels under an oxygen-free furnace atmosphere, the atomic nitrogen can penetrate the surface and increase the nitrogen content of the steel.

The yielded surface nitrogen content depends on three factors: the alloyed contents of the stainless steel, temperature, and the partial pressure of the nitrogen. Calculated along the lines of the Sievert's Law, the square root of the surface nitrogen content is proportional to the nitrogen partial pressure, $N_S \sim \sqrt{P_{N_2}}$, and the nitriding depth, in accordance with Fick's Second Law, increases with the square root of the treatment duration (√t).

The solubility limit of the nitrogen austenite required for the formation of the highest possible surface nitrogen content can be found in the equilibrium diagram, which can be determined for each steel type using the Thermo-Calc software.

Temperature, pressure and alloying element content have to be coordinated in order to solve enough nitrogen and to avoid precipitation of nitrides (Fig. 2).

The typical process parameters for the SolNit process are temperatures between 1922 °F to 2102 °F (1050 °C and 1150 °C), nitrogen partial pressures (N_2) of 0.1 bar to 3 bar abs., and diffusion times between 15 minutes and four hours. This process achieves a nitrogen depth of .008 inches to .1 inches (0.2 mm to 2.5 mm). The surface hardness of martensitic steels lies between 54 HRC and 61 HRC, for austenitic and duplex steels between 200 and 350 HV.

An important step in the SolNit process is the quenching step. As the temperature drops, the solubility of the austenite decreases. At this point, the quenching speed must be very fast in order to prevent chromium nitride precipitation. Thus, quenching in oil or high-pressure gas quenching with rapid gas flow is necessary.

The rapid quenching of martensitic stainless steels yields a nitrogen-containing martensite with a large portion of retained austenite. This amount of retained austenite can be reduced by deep cooling and tempering at temperatures of up to 842 °F (450 °C). High surface hardness values are reached through this process. Although, at these high-nitriding temperatures certain problems can occur due to the grain growth. If an application requires a high-quality toughness, the grain size can be refined by a double-hardening treatment.

In austenitic steels, the hardness improvement is considerably lower because thermal processes cannot reshape the grain coarsening. In two-phase austenitic-ferritic steels (e.g., duplex steels), the grain structure in the core remains relatively stable.

Comparability of SolNit Treatment Results

At this time, there is no standard measure for the SolNit depth hardness; therefore, users apply different methods. It has been proposed that a workgroup, charged with developing a general measuring method, should be built to improve the comparability of the process results.

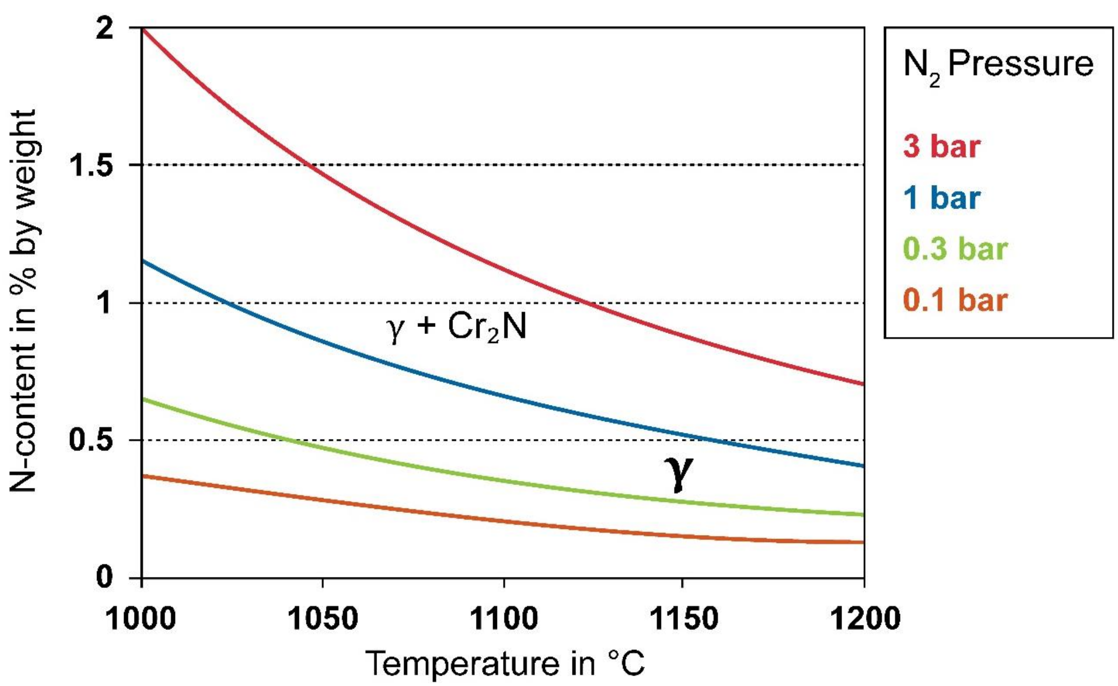

Figure 2: *Precipitation of nitrides in dependence on nitrogen content, temperature and nitrogen partial pressure for martensitic steel [2].*

Applications

During the last few years, the application of the SolNit-M procedure has gained importance in the following areas:

- Chemical industry
- Textile processing
- Food processing industry (e.g., milk and dairy products)
- Machine Building industry
- Architecture
- Household and kitchen appliances
- Medical industry

Figure 3 shows the typical hardness profiles for the corrosion-resistant, martensitic steels (X6Cr17, X14CrMoS17, X15Cr13 and X20Cr13) after a SolNit treatment. The various levels of carbon, chromium and ferrite of these steels determine the core hardness values, which are between 220 HV and 510 HV.

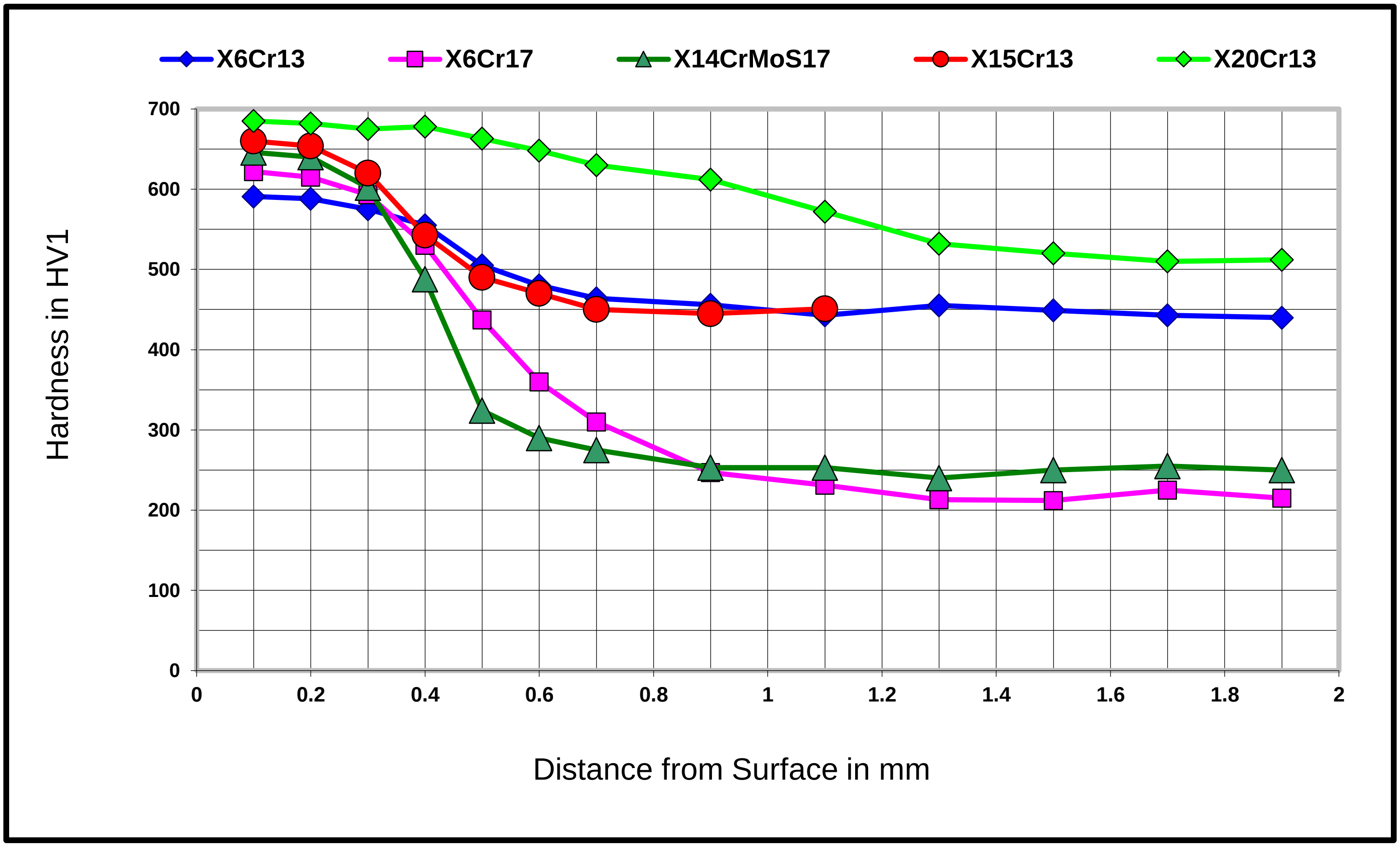

Figure 3: *Typical hardness profiles after SolNit-M treatment*

As mentioned earlier, mechanical masking is not possible. The interesting question is: to what extent grooves, scoring and blind holes are nitrided? This question was investigated using a sample with an open hole (Fig. 4). A hardness profile of the entire wall thickness was recorded at three defined measurement points distributed along the length of the sample (Fig. 5).

The following two conclusions can be drawn from the results:

- The same nitriding conditions exist on both the internal and external diameter.
- Open and blind holes can be uniformly nitrided without problem, whereby the limits in respect of L/D ratios must still be investigated.

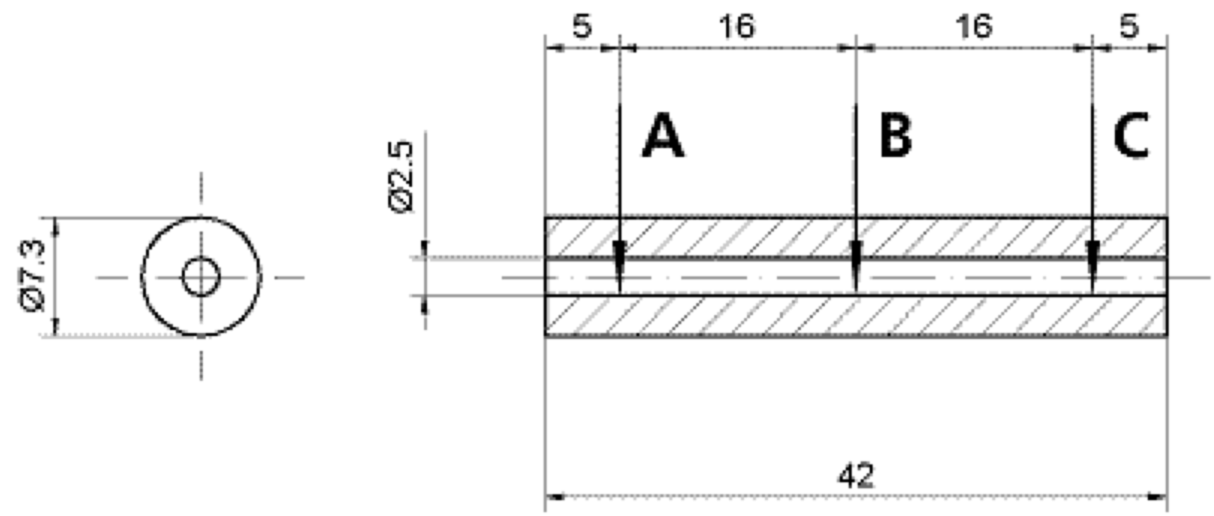

Figure 4: *Sample with a ø 2.5 mm hole. The measuring points are marked.*

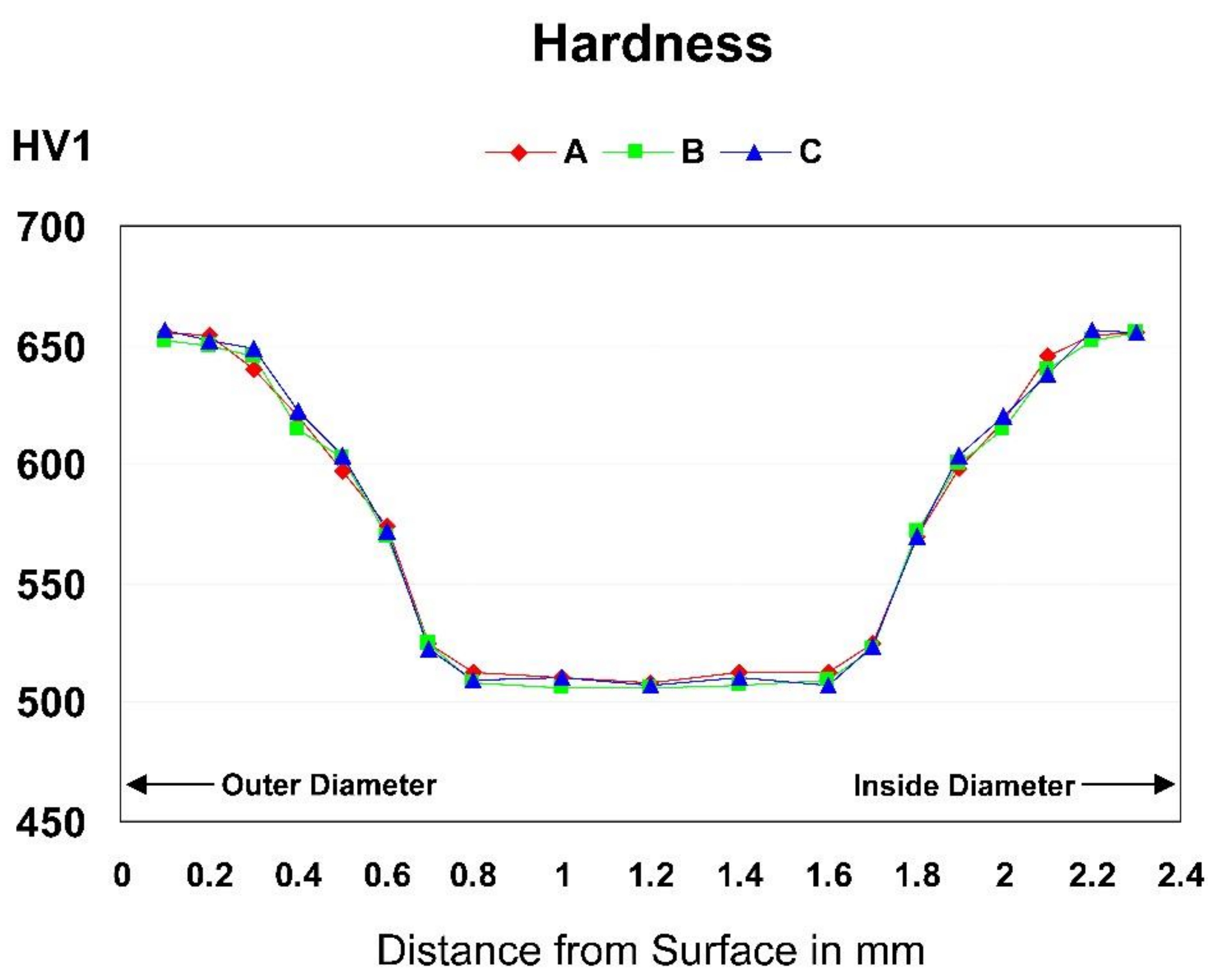

Figure 5: *Hardness profile of three measuring points*

Summary

- The solution nitriding process, SolNit®, is performed in the austenitic phase of steel. At temperatures above 1922 °F (1050 °C), the thermal dissociation of nitrogen can be used to transfer into and solve nitrogen in stainless steels.
- Nitrogen case depth up to .1 inches (2.5 mm) can be reached in 24 hours.
- The surface nitrogen content for a given steel grade and temperature, Ns, depends on the nitrogen partial pressure.
- Martensitic and ferritic stainless steels form after solution nitriding a nitrogen-enriched surface layer, quenching the layer, sub-zero treatment and tempering. This process version can be described as nitrogen case hardening, which is different from conventional case hardening with carbon because using nitrogen increases the corrosion resistance. This process can be used for the heat treatment of stainless bearings, tools and gears.
- Austenitic and duplex stainless steels form a stable, high-strength and ductile surface layer; this layer gives a good resistance against cavitation and erosion, improving the properties of pumps, valves and other parts of fluid flow engines.
- Surface hardness repeatability was found, as well as the nitrogen profile and hardening depth, for small, blind holes.
- Compared to carburizing processes, the atmosphere during solution nitriding is non-toxic and less volatile because no continuous gas flow or internal oxidation is necessary.

References

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[2] Berns, H.; Juse, R.L.; Edenhofer, B.; Bouwman, J.W.: Verfahrenstechnik und Stîhle f½r das Randaufsticken. HTM 54 (1999) 3. S. 128-135.

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About
Ipsen

Ipsen designs and manufactures industrial vacuum and atmosphere heat-treating systems, supervisory controls and predictive maintenance software for many industries including Aerospace, Automotive, Commercial Heat Treating, Energy and Medical. Leading the industry with more than 10,000 furnaces installed worldwide, with production locations on three continents and representation in 34 countries, Ipsen is committed to providing 360° support for customers.

Ipsen Customer Service provides aftermarket support for any brand of vacuum furnace through process development, factory layout planning, installation and start-up assistance, training, replacement parts, hot zones, controls and instrumentation upgrades, mechanical retrofits and furnace refurbishments. With a global team of more than 120 field service technicians, Ipsen employs the largest and most skilled aftermarket team in the business providing quick and easy access to troubleshooting, maintenance, repairs, instrument calibrations and temperature uniformity surveys. Ipsen's aftermarket support helpline also provides remote assistance for customers in any location.

Ipsen
984 Ipsen Rd.
Cherry Valley, IL 61016
Toll Free: 1-800-727-7625
Sales@IpsenUSA.com
IpsenGlobal.com

SN1021