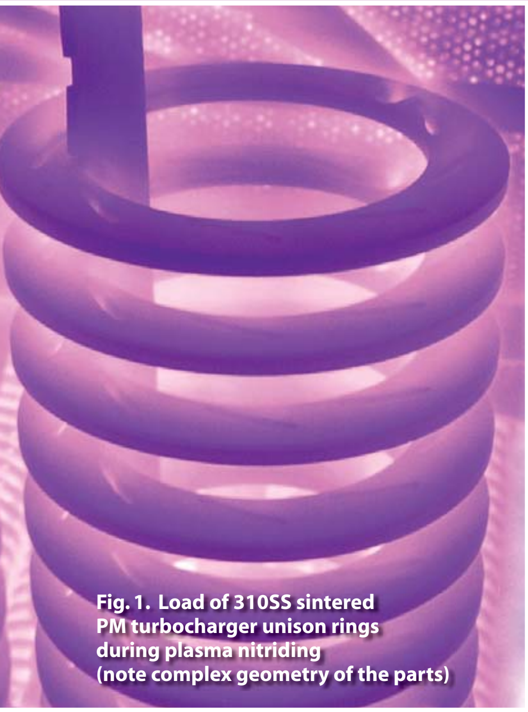

Fig. 1. Load of 310SS sintered PM turbocharger unison rings during plasma nitriding (note complex geometry of the parts)

Plasma, Gas Nitriding and Nitrocarburizing for Engineering Components and Metal-Forming Tools

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Wear, corrosion and fatigue properties are strongly dependent on surface quality and its modifications.[1] Thermochemical methods such as gas and plasma nitriding allow for enhancement of these properties in most severely loaded (mechanically and/or chemically) applications without causing any changes in dimensions of the treated objects.

Gas nitriding, despite its long history, is still a subject of extensive studies. There are publications presenting new inventions, which have made the process a fully controllable method in the last 30 years.[3,4] Plasma nitriding, on the other hand, is growing fast as a well-controlled, low nitriding-potential process, which also has many other benefits.[5] Modern nitriding methods are now described in academic textbooks as well as in many other publications.[1-10]

Differences in the mechanism of plasma- and gas-nitriding methods have an impact on the usage of both processes. Focusing on the most proper applications characteristic for each method is important. Plasma nitriding is called a low nitriding-potential process because of its natural ability to produce layers with the thin compound zone.[5] Also, penetration of small cracks and porosities with plasma nitriding is very limited. The process is therefore well-suited for treating low-density powder-metal/sintered products. Plasma's ability to activate passive surfaces makes it very useful in hardening stainless steels and other nonferrous alloys (titanium and nickel). The method is also known for its usage when effective selective hardening is required.

Alternatively, the controllable gas-nitriding method allows for precise nitriding at a low and a high nitriding potential. It is very effective in achieving layers with a thin or thick compound zone in applications where 100% surface treatment is required. This is especially the case when a much thicker compound layer is required than is possible to produce with plasma nitriding.

Modern applications of the two nitriding methods – plasma and gas – should mostly be based on technical rationale of the specific requirements, which can be achieved economically using the most proper method in a given situation.

Applications of Plasma Nitriding

Applications of plasma nitriding are very broad. Plasma nitriding is the answer to many problems caused by the abrasive wear of various tools used in the plastic and metal-forming industries. Examples involve feed screws, barrels, backflow valves, nozzles, molds and other components of plastic machinery subjected to conditions of extreme wear from fiberglass-containing plastic.

Products requiring a thin compound layer and extensive masking are growing in demand (e.g., big, forged crankshafts in which threaded holes and counterweights need to be masked). Despite its universality, the best applications of plasma nitriding are those products made of stainless alloys, sintered metals or titanium when the parts are large and selective hardening is required.

Stainless Steel Products

Both plasma and gas nitriding can be used to treat stainless steels. Plasma nitriding, however, has unparalleled ability to activate the most difficult alloys. The gas method, in those situations, needs an additional activating step with very aggressive chemicals or extensive mechanical blasting before the process can start. The sufficient sputtering rate of stainless steel can be achieved in nitrogen-hydrogen plasma to cause activation of its surface. Therefore, plasma can be considered as a method especially suited for treating those alloys. A good example would be 310 steel, such as the sintered-metal unison rings shown

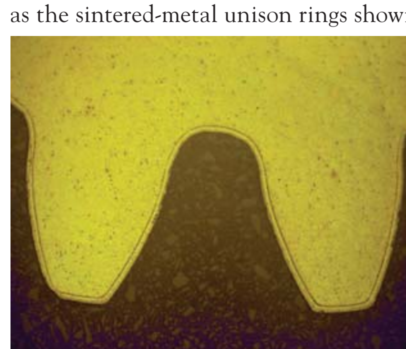

Fig. 2. Photomicrograph of plasma-nitrided 17-4 PH steel gear with diametral pitch (number of teeth per inch of pitch diameter) of 48 (50x; 3% nital)

Fig. 3. Plasma-nitrided aircraft hydraulic components for steering system made of the $\alpha+\beta$ titanium alloys

Fig. 4. Large internal 4340 steel gear for power energy application being loaded into the plasma-nitriding vessel (note extensive mechanical masking on the outside of the gear)

in Fig. 1 and 17-4 PH small-pitch gears shown in Fig. 2. Despite complex part geometry, plasma nitriding produced a uniform layer in both situations.

Titanium-Alloy Products

Frictional properties as well as corrosion resistance of titanium-alloy products are significantly enhanced by plasma nitriding.[7] Nitriding leads to formation of the multi-zone layer, the outer portion of which is the TiN-type nitride with a characteristic gold color. Figure 3 shows titanium-alloy components after plasma nitriding.

Large Products Requiring Extensive Masking/Selective Hardening

Until recently, case hardening has been used for heat treating gears, but plasma nitriding has shown increasing interest because of minimal to no distortion. This means there is no need to grind the tooth form after heat treatment, and the products can be put directly into service. The technique can be applied to very small and very large gears (Figs. 2, 4). Typical gear failure modes are bending fatigue, pitting, micropitting, scuffing and wear.[8] Nitriding increases wear and scuffing (scoring) resistance of the tooth flanks, bending fatigue resistance at the tooth root as well as the rolling-contact fatigue (RCF) resistance of the gear-teeth surface. RCF typically leads to surface or subsurface-induced cracks, which are greatly minimized by the presence of the nitrided layer. Nitriding also produces high resistance to tempering (i.e. increases the resistance of the steel to softening at slightly elevated temperatures).

Stress studies on nitrided case have shown an area of compressive stress beneath the surface in the diffusion zone, and stress values are highest in the most highly alloyed steels.[9] Plasma-nitrided gears made from an appropriate material can replace carburized and carbonitrided gears. A comparison of tooth-flank fatigue strength for different types of steel showed the effect of case depth, core hardness and microstructure on fatigue strength.[9]

Load-bearing capacity at flank and root of the gear tooth is affected by the thickness of the compound zone (white layer). Plasma-nitrided gears with a maximum of 1-micron compound-zone thickness have the highest load-bearing capacity.[9] Nitrided gears do not require as much case depth as carburized or other case-hardened gears. Tensile strength of core material prior to nitriding should be taken into account in assessment. Some of the large gears for power energy applications require local protection from nitriding to allow for finishing operations or for reducing risk of any distortion. This is achieved by mechanical masking (Fig. 4).

Large Metal-Forming Tools

Metal-forming tools, like large automotive stamping dies, are often used for forming auto-body parts made of advanced high-strength steels (AHSS) such as dual phase (DP), transformed induced plasticity (TRIP) and some other high-strength steels (HSS). Contact stresses required in those operations exceed contact strength of the galvanically applied chromium layers typically used in older applications. In such situations, plasma nitriding is the most efficient treatment for improving durability and performance of the tools. Many of the tools are often made of gray cast irons. During plasma treatment, these materials maintain their surface roughness unlike in gas nitriding, which may result in a significant increase in roughness.[10] Very large stamping dies can be treated in plasma chambers as seen in Fig. 5.

Application of Gas Nitriding/ Nitrocarburizing

Small Parts Requiring All-Over Treatment

Gas nitriding allows for a good penetration of the nitriding atmosphere around the most geometrically complicated loads. Therefore, the method is very efficient in treating large quantities of small parts, especially those made of low-carbon steels. Gas-nitriding cycles for treating these parts require a high nitriding potential for producing a nitrided layer with a 0.010- to 0.030-mm compound zone. Typical applications include transmission parts that require enhanced wear and fatigue resistance, such as those used in earth-moving vehicles (Fig. 6).

Fig. 5. Cast iron automotive stamping dies after plasma nitriding

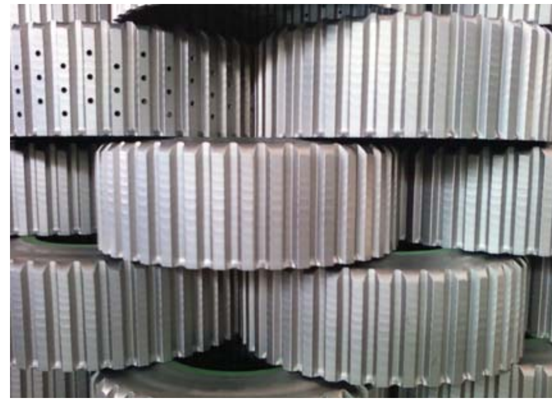

Fig. 6. Load of the 1008 steel automotive transmission hubs after gas nitro-carburizing

Large Parts Requiring Anti-Galling and Corrosion-Resistance Properties

In many of those applications, good surface properties of the product can only be achieved if a significantly thick compound layer of $\varepsilon\text{-}Fe_2N_{1-z}$ has an additional layer of magnetite for the enhanced corrosion resistance. These requirements can be easily met by a multi-step treatment in a furnace with the automatic control of the nitriding and oxidizing potentials shown in Fig. 7. Nitrocarburizing with post oxidation often replaces different types of electroplating like chromium and zinc with chromate passivation.

Summary

Available nitriding/nitrocarburizing techniques should be used in their best-suited applications to achieve desired engineering effects in the most economical way. Therefore, it is of paramount importance that an analysis of the product design and its manufacturing sequence is agreed upon with heat-treating experts to achieve these goals. **IH**

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Fig. 7. Long, low-alloy steel shafts used for hydraulic cylinder rods after gas nitrocarburizing with post oxidizing

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