New Approaches to Nitriding

What you should know about this process now.

Gerald Wolf

The process of nitriding has been used to case harden gears for years, but the science and technology of the process have not remained stagnant. New approaches have been developed which are definitely of interest to the gear designer. These include both new materials and new processing techniques.

A list of the desired properties of a material/heat treat combination desired for high performance gearing should contain the following:

- High load carrying capabilities,
- High resistance to scoring and wear,
- Good low and high cycle endurance,
- Good impact resistance,
- Low distortion during processing,
- Predictable size change,
- Low cost,
- Easy availability.

Nitrided alloy steel can meet many of these requirements. The thin, hard case it forms is highly resistant to both scoring and wear. The base material can be core-treated to high strength levels, and the residual compressive stresses generated in the case produce excellent long-life fatigue properties; however, because the case depths are shallower, nitrided gears cannot be loaded as heavily as carburized gears. Nitrided alloy steel parts also have improved corrosion resistance and are more resistant to softening from heating. And, most important, because the process is performed at relatively low temperatures and doesn't involve quenching, both distortion and size change are very low and predictable. In most applications, gear teeth are used as nitrided. Therefore, when the total manufacturing cost is considered, nitriding can be more economical than carburizing if operations such as press quenching or finish grinding are eliminated.

Table I — Typical Nitriding Materials and Hardnesses Produced by Nitriding

MATERIAL	NOMINAL COMPOSITION							SURFACE HARDNESS
	C	Mn	Ni	Cr	Mo	V	Al	HR15N
SAE 4142	.42	.88	–	.95	.20	–	–	87–90
4140 MOD	.40	.88	–	.95	1.00	–	–	[illegible]–91
SAE 4340	.40	.70	1.75	.80	.25	–	–	85–90
Nitralloy 135M	.42	.55	–	1.60	.38	–	1.0	92–94
DIN 31CrMoV9	.33	.60	–	1.50	.23	.20	–	91–93
D6-AC	.47	.75	.55	1.10	1.05	.12	–	87 Min.
EMS 64500	.40	.60	–	3.25	.35	.20	–	92 Min.

Early History

The first patent for nitriding dates back to 1913. About ten years later, the aluminum alloy steel called Nitralloy was developed by Krupp. With these materials, a very hard, wear-resistant case could be produced, but for many applications it was necessary to remove the extremely brittle hard surface layer. Then in the 1940s, Dr. Carl Floe at MIT developed a two-stage nitriding process that significantly reduced this brittle white layer. During this same period, the Germans developed a nitriding process, glow discharge nitriding, which employed an electrically generated plasma. After World War II, both General Electric in the U.S. and Klockner in Germany further refined this process, and by the mid-1970s plasma, or ion nitriding, had become a viable option for many applications.

Contemporary Nitriding

Many different nitriding techniques are available today.

Two 137T, 5 D.P. gears just after nitriding. They will be used in a 13,000 HP marine drive.

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The basic process, however, is relatively simple. The material is heated to 900–1100°F in an active nitrogen-rich atmosphere, held for a sufficient time for the nitrogen to diffuse to the desired depth, then slow-cooled.

The case produced in alloy steel contains two zones. At the surface is a very hard compound zone referred to as the white layer. In conventional gas nitriding, this layer consists of a mixture of gamma prime and epsilon iron nitrides. In ion nitriding, the structure of this zone can be controlled to produce a single phase layer of either gamma prime or epsilon iron nitride. Below the compound zone is the diffusion zone containing precipitated alloy nitrides. Both its depth and properties are greatly dependent on the concentration and type of nitride-forming elements in the steel. Primarily these are aluminum, chromium, vanadium, molybdenum and titanium. In general, the higher the alloy content, the higher the case hardness. However, higher alloy contents retard the nitrogen diffusion rate, which slows the case depth development and, thus, requires longer cycle times to achieve a given case depth.

Most gas nitriding performed on gears has been done using the two-stage Floe process. During the first stage, pure ammonia (NH_3) is used as the furnace atmosphere. This dissociates into hydrogen and nitrogen at the surface of the steel, producing nascent or atomic nitrogen (N), which reacts with and diffuses into the steel. Note that molecular nitrogen (N_2) will not react in this

A load of gears being removed from a gas nitrider.

manner. During the longer second stage, dissociated ammonia (H_2 + N_2) is employed to reduce the nitriding potential of the atmosphere.

Today techniques are available which use pure nitrogen blended with other gases to achieve the desired nitriding potential during different stages of the nitriding process. In this way, the optimum case properties can be obtained for the application involved. For example, with contemporary multi-stage nitriding we can precisely control the white layer thickness to a finite amount or, if desired, completely eliminate it without incorporating post-processing procedures.

Similar results can also be obtained using modern ion nitriding techniques. In ion nitriding, the processing is done in a special vacuum furnace which has been backfilled with nitrogen. An electrical voltage between the work and the surrounding vessel ionizes the gas around the work, supplying the nascent nitrogen needed for nitriding. Although initial work with finer pitched gears often produced nonuniform results, these problems have been largely overcome, and the ion process is being successfully employed in the gear industry. For most work, however, gas nitriding is the popular choice.

Material Selection

Most alloy steels can be nitrided. Since the chrome-containing 4140/4145 grade is widely available and responds very well, it is widely used for gear applications. For higher case hardnesses and core strengths, the special nitriding steels such as the German 31CrMoV9, Nitralloy 135M or a custom grade should be used. Table I lists the composition of several materials used for nitrided gearing and the surface hardnesses that can be obtained with them.

Core treating by quench and tempering to a martensitic structure prior to machining is very important. This creates the desired core properties and also improves the response of the nitriding process, producing higher case hardnesses. Several factors must be considered, however, when determining the desired core hardness. The tempering temperature should be at least 50°F over the nitriding temperature to prevent changes during nitriding. Since as the core hardness increases, machinability decreases and the ability to produce stress-free parts becomes more difficult, the most commonly used range for 4140 steel is 30–34 HRC. However, for heavily loaded parts where the higher alloyed steels are employed, it is not uncommon to use core hardnesses in the 36–40 HRC range. One advantage of ion nitriding is that it can be performed at reduced temperatures, allowing the use of lower tempering temperatures during core treating.

When processing parts to be nitrided, one must ensure that all decarburized material has been removed first. This means that as-forged webs and other such areas should either be fully machined, masked to prevent nitriding or carbon-restored during core treating. Another processing consideration is the removal of machining stresses prior to finish machining and nitriding. It is sometimes necessary to stress relieve complex critical parts in the semi-finished condition to minimize their movement during nitriding.

While most nitrided gears are placed into service as nitrided, finishing operations can be performed after hardening. For example, tooth grinding to remove 0.002–0.005" per flank is used to produce large high-performance gears to AGMA Class 15 specs. For improved endurance life, shot peening can be employed if the white layer is controlled to a 0.0005" maximum during nitriding. ⚙

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