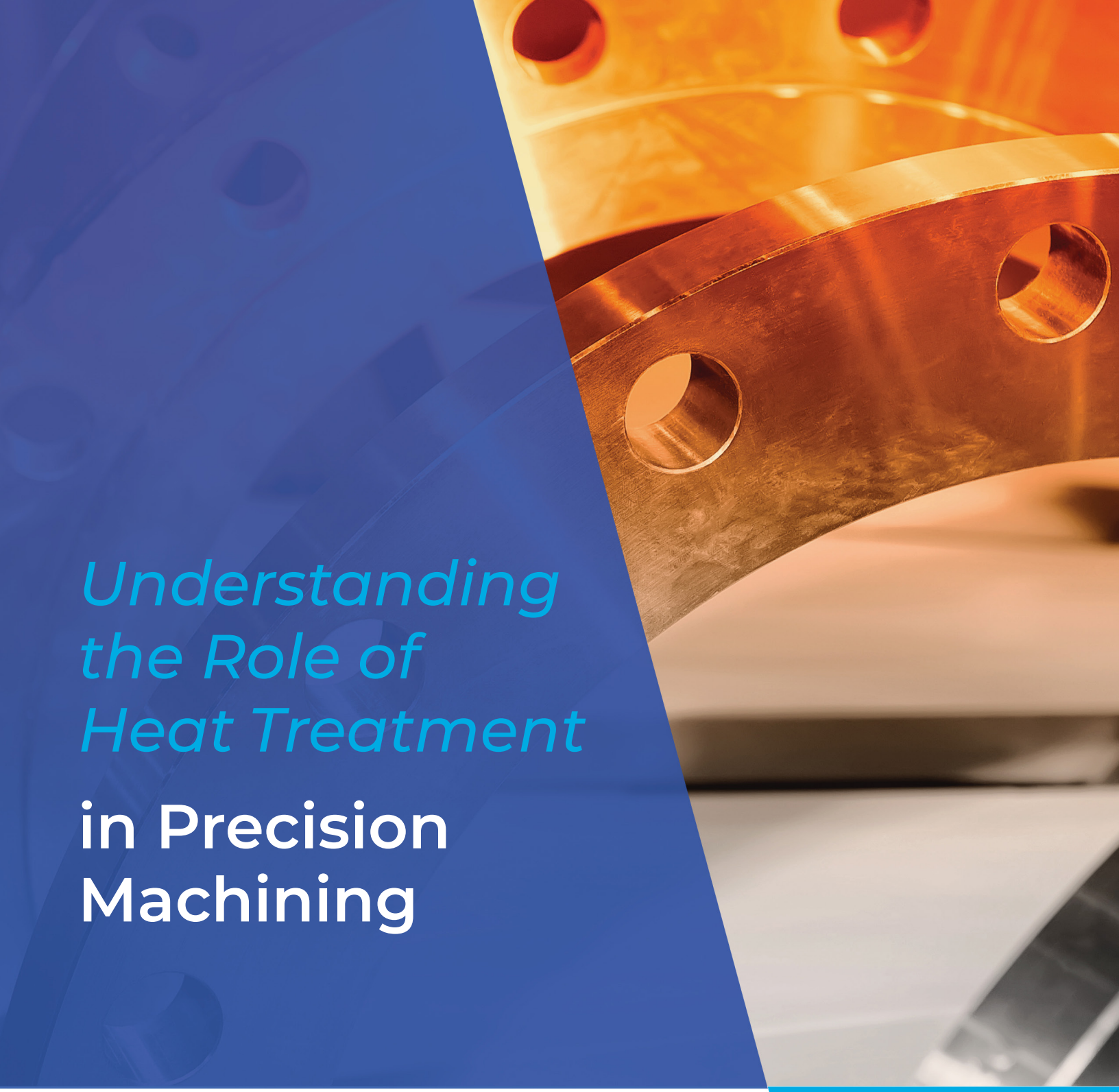


Understanding the Role of Heat Treatment

in Precision Machining

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The strength, durability, and even mass of a part made from steel are determined by alloy composition and microstructure. Composition is established when the alloy is first created, but microstructure is set by heating and cooling.

Heat treatment modifies the microstructure, which alters the properties of the part being made. Precision machined metal parts almost always benefit from undergoing one or more heat treatment processes during manufacture.



This eBook explains the reasons for heat treating precision machined parts, the processes most often used, and what they achieve. Individual sections address:

- *Microstructure and properties*
- *Increasing strength*
- *Increasing wear-resistance*
- *Common applications*
- *Overview of heat treatment processes*
- *Increasing toughness*
- *Heat treatment and precision machining*

Microstructure and Properties

Metals solidify with a granular structure. This determines properties like strength, hardness and ductility. In a ductile alloy the grains are able to move slightly under load. In a very hard structure there is almost no freedom for this to happen, which makes the metal brittle. Strength is related to the load needed to cause movement. Applying a tensile load results in “necking” of the cross-section and eventually, fracture.



When metals are cast the cooling rate varies depending on cross-section and surface area. Regions that cool faster tend to have a finer microstructure while areas slower to cool are more granular. The effect of this is to leave a casting with different properties in various regions.

Machining can alter the microstructure at and close to the surface. Forces imposed by the cutting inserts cause local distortions that leave the surface stressed. If this isn’t released the part may deform enough to cause problems in service.

Overview of Heat Treatment Processes

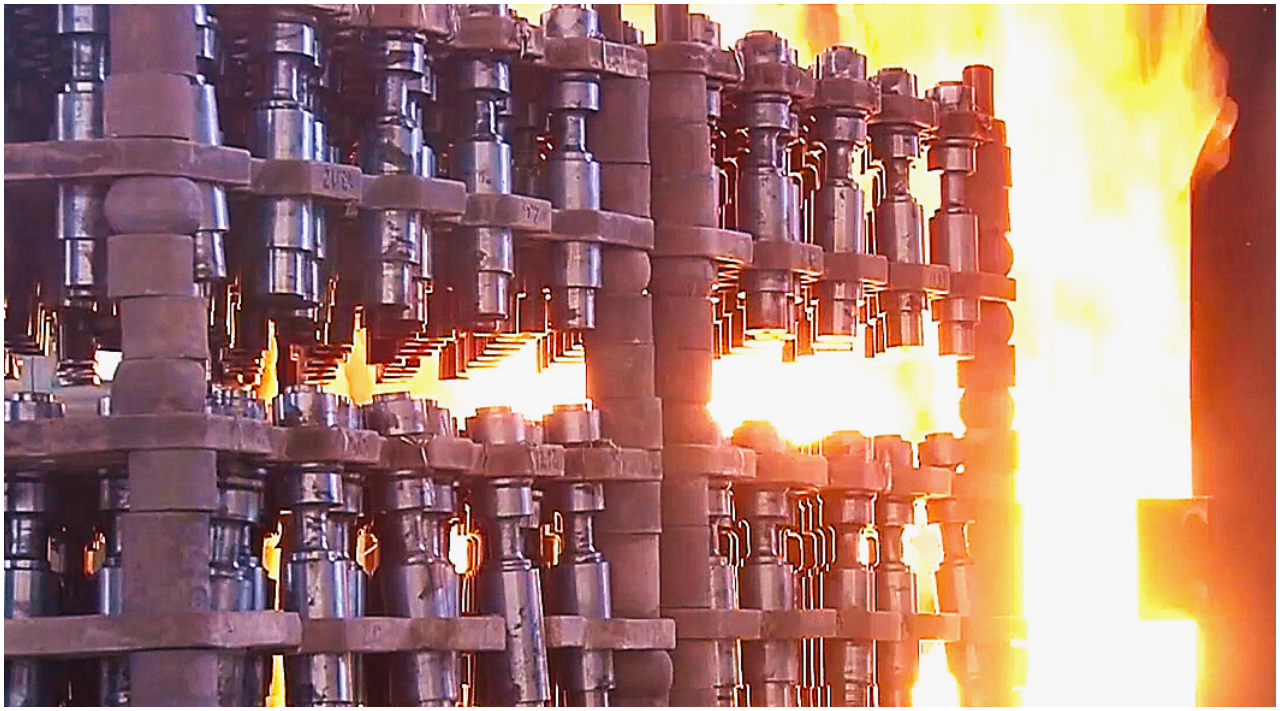
Microstructure can be changed by letting the metal soak at an elevated temperature before cooling. In steel the rate at which grains move and change size is influenced by carbon content and temperature. It's also possible to add elements to the microstructure by performing heat treatment in a controlled atmosphere. Less often, it's useful to encourage segregation of elements within the microstructure, which can also be achieved by heat treatment.



Heat treatment processes all entail heating the metal, letting it soak for a period of time, and then cooling. Soak temperature and duration, optimized for carbon content, bring about the required changes. Cooling rate determines how the microstructure is locked into place.

The atmosphere in which heat treatment is performed will affect the resulting properties. An oxygen-rich atmosphere can promote oxidation, which is avoided by heating in vacuum. Alternatively, air can be replaced with other gases to bring about specific modifications.

It should be noted that heat treatment usually results in an unattractive appearance that needs cleaning and finishing. Scaling is a possibility when conditions are not controlled carefully.



Heat treatment is performed to:

- Increase tensile strength
- Increase material hardness
- Increase wear resistance
- Aid machinability

Individually or together, these improvements can lower manufacturing costs and improve product performance. They may also allow substitution of less expensive metals for highly alloyed compositions.

Increasing Strength

The strength of steel is increased by modifying the levels of ferrite and austenite in the microstructure. This requires precise control of soak temperature and cooling rate, together with knowledge about the level of carbon in the material.

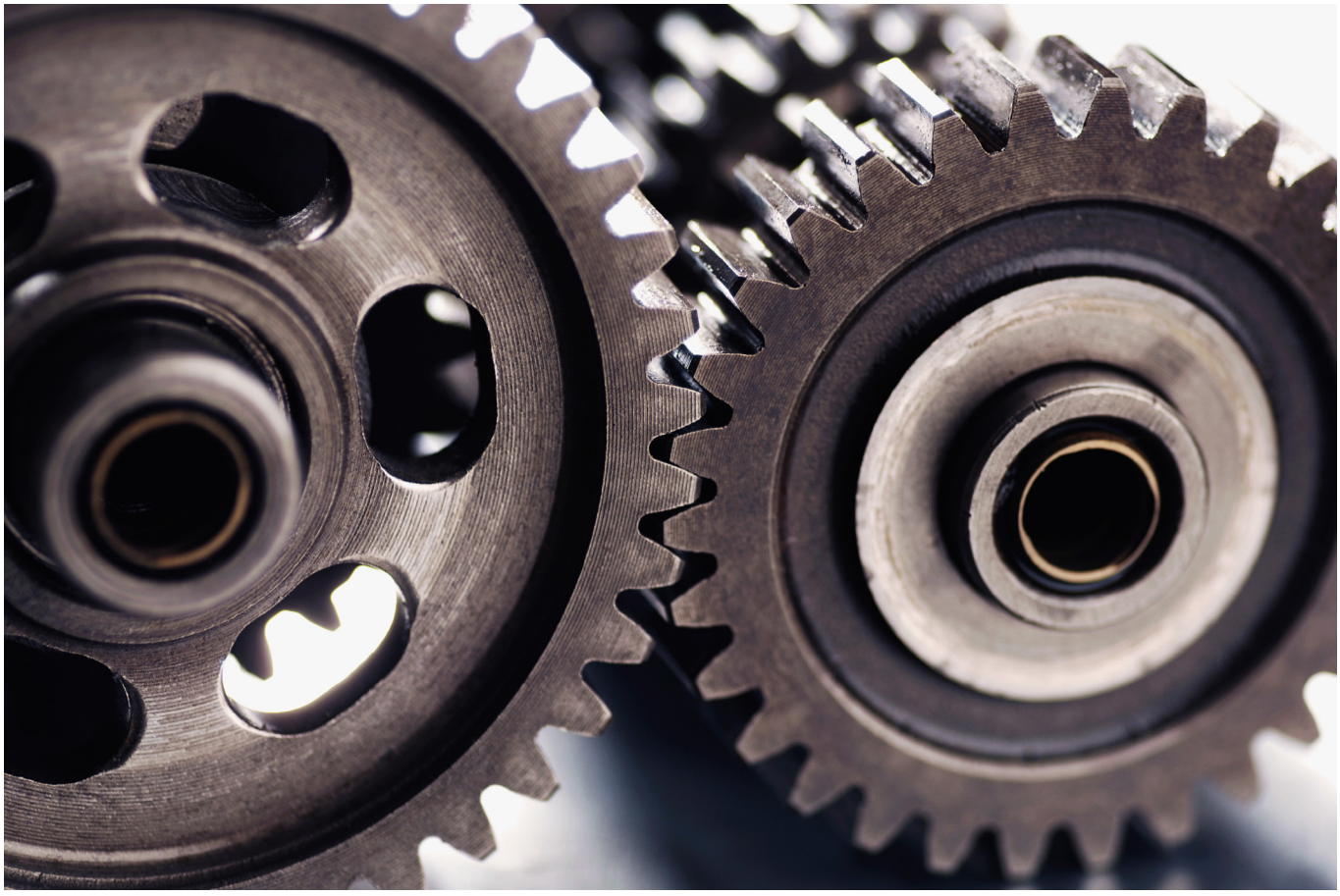
“Annealing” is a way to reduce hardness and at the same time raise tensile strength. It involves a very slow cool down after soaking.

Increasing Toughness

A tough material is one with good impact resistance. Toughness is achieved through “tempering”. This is a heat treatment performed after quenching has raised hardness and made the material more brittle.

Increasing Wear-Resistance

When a part is subject to sliding contact, as is the case with gear teeth for example, long life is achieved by raising surface hardness. This is done by “quenching”, which refers to rapid cooling from an elevated temperature. The depth of hardness achieved is related to time spent soaking at temperature and the type of quench. Water or oil quenching provides rapid cooling, air quenching is slower, and for even slower cooling, parts can be buried in an insulating material like sand.



Case hardness can be raised by modifying alloy composition at the surface. This is done by carburizing, which adds more carbon, or nitriding, which does the same with nitrogen.

Heat Treatment and Precision Machining

Heat treatment is used in conjunction with precision machining for four reasons:

- To save time and money through faster metal cutting / metal removal
- To improve predictability/ consistency
- To remove residual stress
- To facilitate grinding, for superior surface finish and precision

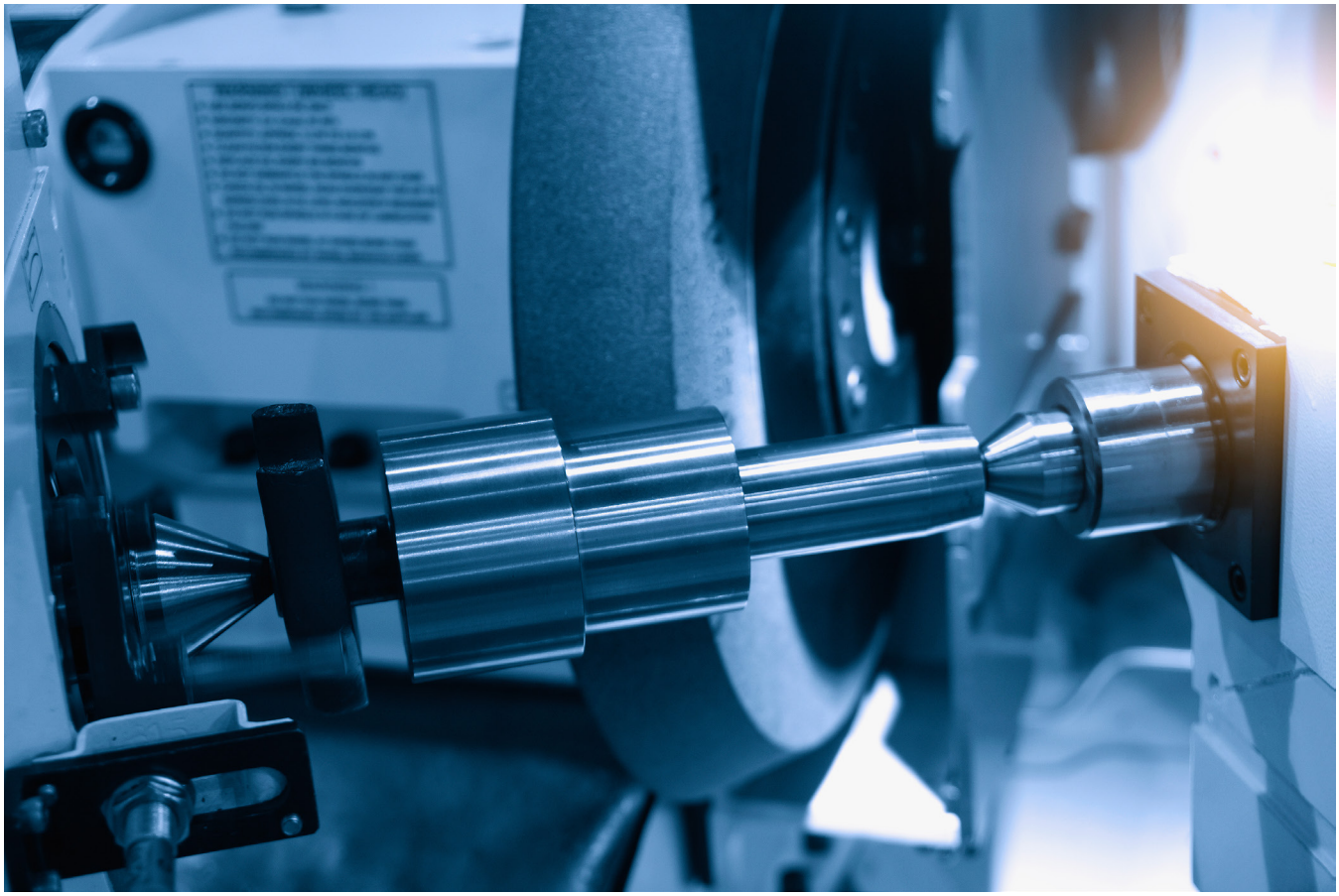
Machining very hard metals requires high cutting forces and low speeds and feed rates. In extreme cases conventional cutting isn't possible, leaving grinding and electro-discharge machining (EDM) as the only options. Although an additional processing step, softening the workpiece through annealing can save money by enabling cost-effective milling and/or turning.

When machining castings, the variations in grain size that result from different cooling rates pose challenges. Harder regions will need different tool geometry to that used in softer areas, and also lower speeds, feeds, and depths of cut.

To overcome this, castings will often undergo a "normalizing" heat treatment. In this process a long soak at temperature produces a more uniform microstructure that can be machined faster and with less risk of tool chipping or breakage. If needed, hardness and strength can be increased after machining through appropriate heat treatment.

Machining, particularly at high metal removal rates, can leave residual stresses in the workpiece. This may distort surfaces that should be flat and/or smooth, like seating surfaces, flange faces and shafts. Stress relief annealing, or just stress relieving, heat treatment dissipates these stresses, so improving final part accuracy.

When the part specification calls for very smooth surface finishes, high accuracy, or both, these are usually achieved by grinding and possibly honing or polishing. Softer metals don't grind well, having a tendency to tear rather than fracture, which leaves a rough surface and "gums up" the grinding wheel.



Raising surface hardness through heat treatment makes it easier to grind and maintain tight tolerances on softer alloys.

Common Applications

Heat treatment can make parts last longer by reducing the wear they experience, and it can allow them to be smaller by increasing their strength. It can also improve impact resistance by making them tougher.

Higher wear resistance is important in parts like gears where teeth flanks slide against one another. Shafts where hubs slide axially or rotate in place are another example. Valve bodies and pump housings will also last longer when made from harder alloys.



High hardness and toughness are desired in surfaces subject to impacts, especially when they need to seal. Valves, valve bodies and valve spools are good examples, as are hubs and shafts.

With higher strength material the designer can reduce part dimensions, which reduces mass. This is useful in automotive applications, and is of particular relevance for aerospace parts.

Explore Heat Treatment Options During Design

Heat treatment is a necessary aspect of the manufacture of almost any precision machined metal part. It can be used to get the metal into a better condition for machining, to enable production of very smooth surfaces and maintenance of tight tolerances, and to improve the properties of the finished part.



As a complement to our extensive precision machining services, we offer a wide range of heat treatment options. These include hardening, annealing and normalizing, and can be performed in controlled atmospheres. Heat treatment of aluminum alloys is also possible.

Heat treatment should always be considered during the design process. It may permit the use of less costly alloys and can simplify machining while improving part durability and functionality. As a leader in casting and precision machining, Impro has both the expertise and resources to advise on and undertake heat treatment. Contact us to learn more.

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