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Bainitic Bearings

Bainitic bearings, produced through a well-designed austempering process, show great potential as an alternative to traditional, martensitic bearings. In bearing-quality steels, bainite can exceed hardness values of 60 HRC. Comparing bainite to tempered martensite at equivalent hardness, bainite tends to have competitive rolling contact fatigue properties, superior resistance to environmental embrittlement, enhanced tensile properties, and improved fracture toughness.

What is Austempering?

Austempering is an isothermal heat treatment that, when applied to steel, produces lower bainite which is a combination of carbon super-saturated acicular ferrite and uniquely oriented, nanosized carbides. With proper heat treatment, lower bainite can be stronger and tougher than comparable martensitic structures conventionally developed through quench & tempering or marquenching heat treatments. A schematic of the austempering process for AISI 52100 is shown in **Figure 1**.

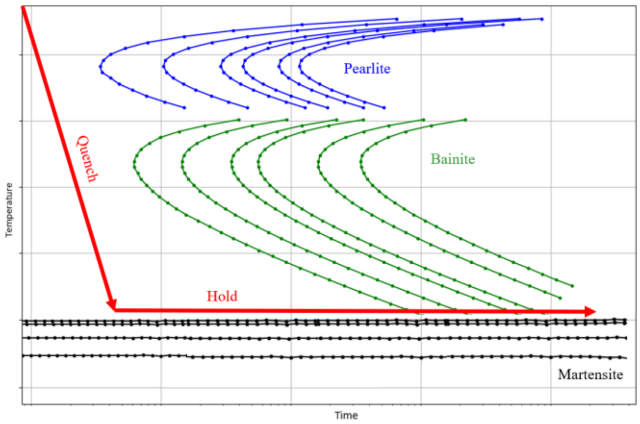

Figure 1: Steel components are heated to red hot and held at temperature in a protective atmosphere before quenching into a molten salt bath above the martensite start temperature. The temperature of the salt bath and transformation time within it are selected to deliver optimal bearing properties.

Minimize Quench Cracking and Distortion

Bainitic bearings produced through an austempering heat treatment can significantly reduce distortion and quench cracking compared to martensitic bearings.

Martensitic heat treatments tend to promote more severe and less predictive distortion due to the nonuniform transformation during the crystallographic phase change from FCC austenite to BCT martensite. In severe cases, the detrimental tensile residual stresses can accumulate at critical stress concentrations and result in quench cracking.

In contrast, austempering does not induce residual tensile stresses nor does it exhibit non-uniform transformation. Before the transformation begins, there is a small incubation time allowing the entire bearing to equalize in temperature. As the transformation progresses, the entire bearing transforms nearly simultaneously. This transformation results in a slight, uniform expansion as the atoms rearrange from a more densely-packed crystal structure to a less densely-packed crystal structure. This simple and predictable growth allows designers to model the volume change in advance and plan for it in the original machining step. In fact, the austempering process can develop beneficial compressive residual stresses near the surface. A comparison between conventional martensitic heat treatments and austempering is given in **Table 1**.

Optimize Mechanical Properties

At equivalent hardness, bainitic bearings have a greater tensile strength, yield strength, elongation, and Charpy impact toughness (**Table 2**) than martensitic bearings. Similarly, expedited rolling contact fatigue testing demonstrates that bainitic bearings have competitive rolling contact fatigue properties (**Figure 2**) and have a higher resistance to rolling contact fatigue failure in non-ideal conditions including hydrogen embrittlement and inadequate lubrication.

Table 1: Heat Treatment Comparison

	Quench & Temper	Marquench	Austemper
Microstructure	Tempered Martensite	Tempered Martensite	Lower Bainite
Distortion	Higher	Lower	Lowest
Quench Cracking	Higher	Lower	Lowest
Transformation	During Quenching	During Air Cool	During Hold
Controlled Air Cool	Sometimes	Yes	No
Temper	Yes	Yes	No

Table 2: Mechanical Properties of AISI 52100

Heat Treatment	Surface Hardness HRC	Tensile MPa [ksi]	Yield MPa [ksi]	Elongation %	Unnotched Impact J [ft-lbs]	Retained Austenite Vol %
Standard Marquench	59.9 ± 0.4	2157 ± 239 [312.8 ± 34.7]	1873 ± 195 [271.7 ± 28.3]	1.4 ± 0.3	84.7 ± 16.5 [62.5 ± 12.2]	2.73 ± 0.38
Standard Austemper	59.9 ± 0.7	2460 ± 25 [356.8 ± 3.6]	2150 ± 30 [311.8 ± 4.3]	4.1 ± 1.0	183.4 ± 58.2 [135.3 ± 42.9]	1.51 ± 0.49

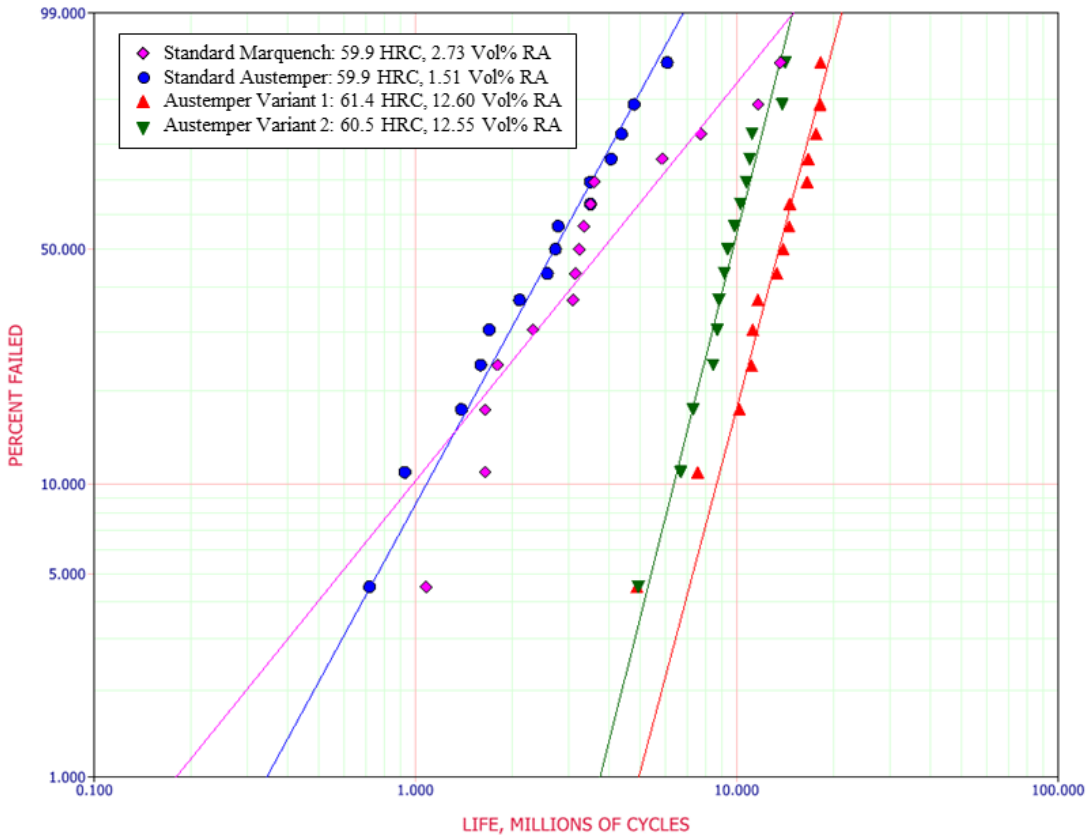

Figure 2: A Weibull plot, generated by expedited Three-Ball-On-Rod testing, details the rolling contact fatigue life for four AISI 52100 heat treatment variants. The Standard Austemper and Standard Marquench samples had relatively equivalent rolling contact fatigue lives at 10% failure (L_{10} life) while Austemper Variants 1 and 2 increased the contact fatigue life by 760% and 540%, respectively.

Maximize Thermal Stability of Retained Austenite

As precision-machined components, any dimensional change to the bearing prior to or during operation can significantly reduce its life and the life of the component that it is facilitating.

Because the carbon content of the retained austenite in bainite is higher compared to the retained austenite in martensite and its morphology is predominately film-type, the retained austenite in bainite is significantly more thermally stable in cold environments. In fact, one study showed that retained austenite in bainite can remain untransformed at temperatures near absolute zero. With this increase in dimensional stability at low temperatures, designers have the opportunity to relax retained austenite volume fraction specifications and to benefit from the mechanical advantages of TRIP effects.

Austempering Variations

While austempering does not require a temper or a controlled air cool, a prolonged quench time may be required for a complete bainitic transformation. In response, novel austempering variations have been developed that reduce the cost of the bearing by either decreasing the total heat treatment time or by substantially increasing its rolling contact fatigue life, with many variants obtaining both (**Figure 2**) Contact Aalberts surface technologies at https://aalberts-ht.us/ for more information.

Further Reading

J. Lipshaw, K. Hayrynen, S. Metz, "A Review of Austempering for Bearing Applications", 1st ASTM Bearing and Transmission Steels Technology Symposium STP 1649 (2024), https://www.astm.org/stp164920220090.html