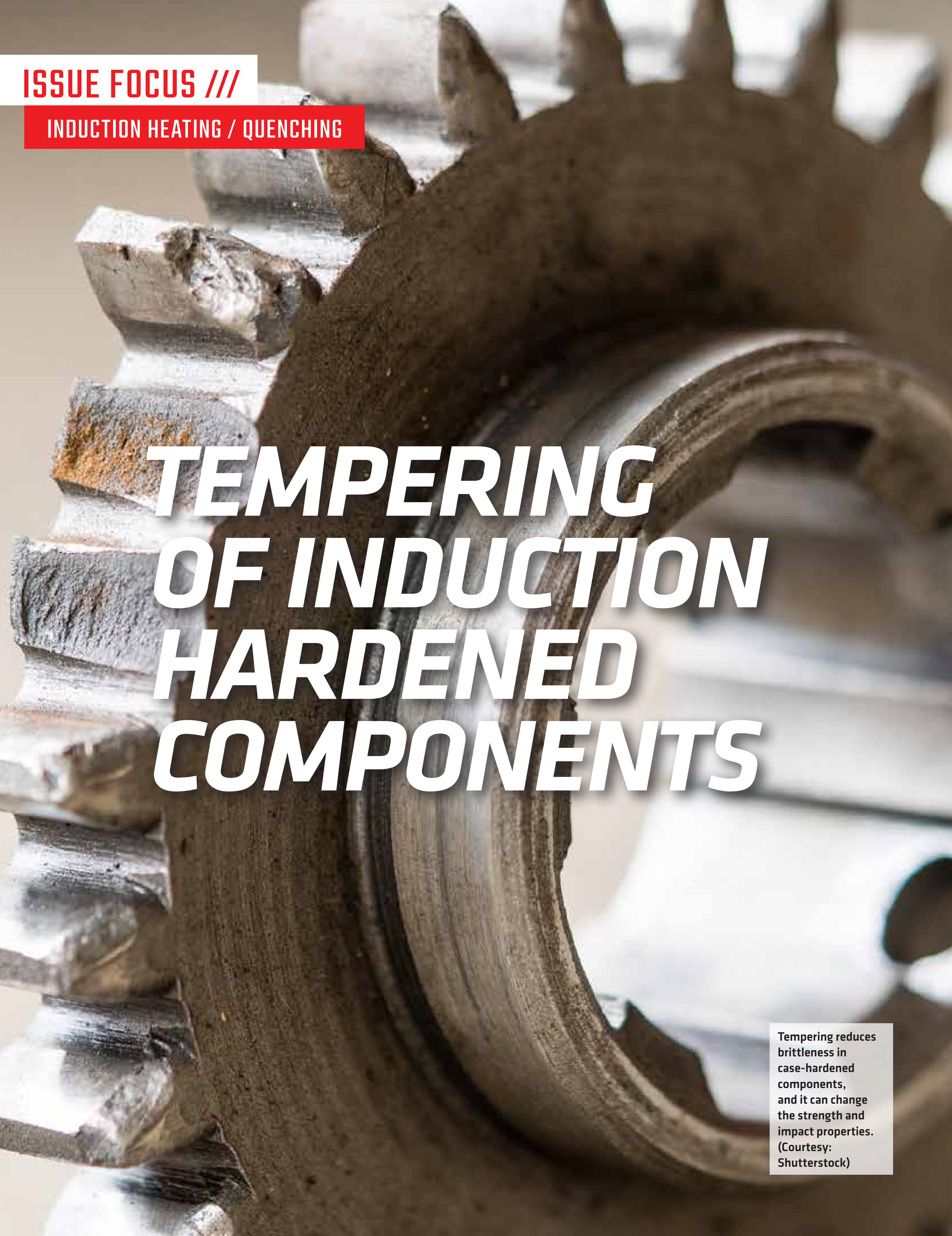
TEMPERING OF INDUCTION HARDENED COMPONENTS



Tempering reduces brittleness in case-hardened components, and it can change the strength and impact properties. (Courtesy: Shutterstock)

Tempering reduces brittleness in case-hardened components, and it can change the strength and affect properties, but more importantly, it can eliminate the tendency for cracking immediately, or shortly after, hardening.

By GREGORY FETT

Tempering is a subcritical heat-treatment process used to reduce brittleness in case-hardened parts. Tempering is normally done between 280°F/138°C and 450°F/232°C, and 350°F/177°C is probably the most widely used temperature. The time is usually about 1 hour or more at temperature.

"Untempered martensite is not fit for service." This is undoubtedly something every materials or metallurgical engineering student has heard at some time. It is a well-accepted fact. However, it is not quite true. Carburized gears were produced without tempering for more than 40 years. This was due to a desire to keep the surface hardness as high as possible. Induction hardened shafts made from 1035 plain carbon steel were also left untempered as were 1038 shafts if the as quenched hardness was 57 HRC or less. Tempering was eventually introduced on carburized gears, but it had nothing to do with mechanical properties, instead, it was a related step in the manufacturing process. Tempering was also uniformly employed on all induction hardened shafts when the 1035 steel grade was eliminated due to low hardenability concerns.

Once in a great while, it may be beneficial to be ignorant so you do not realize what you are about to do will not work, because, sometimes, you do it, and you discover it does actually work. This would be the exception rather than the rule. However, it never hurts to challenge well known facts, especially if little or no data is available.

Tempering does reduce brittleness in case-hardened components, and it can change the strength and impact properties. More importantly, it eliminates the tendency for cracking immediately, or shortly after, hardening. There was a time when the tempering furnace stopped working while heavy truck axle shafts were being induction hardened. The next day, a small percentage of the 15B41 shafts exhibited cracks in the flange radius, but all 1541 shafts were crack free. With induction-hardened parts, quench cracking is very dependent on the steel carbon content, hardenability, and any stress concentration in the part. Oil-quenched carburized parts have no danger of cracking if tempering is delayed or not used, unless the steel carbon content allows the core hardness to increase well above 55 HRC.

The effects of tempering on through-hardened plain carbon or alloy steels loaded in tension are well documented [1]. As the tempering temperature increases, the hardness decreases, as does the ultimate and yield strength while the elongation and reduction of area increases. Data in the untempered condition is typically not provided as it is assumed it will never be used. In this article, we will examine the effect of tempering temperature on both carburized and induction-hardened steels loaded in torsion and in bending. The effect of tempering is much different than in tension [2, 3].

CARBURIZED PARTS LOADED IN BENDING

Figure 1 shows the dimensions of the U-Notch test bar that was used to characterized the bending properties vs. tempering temperature

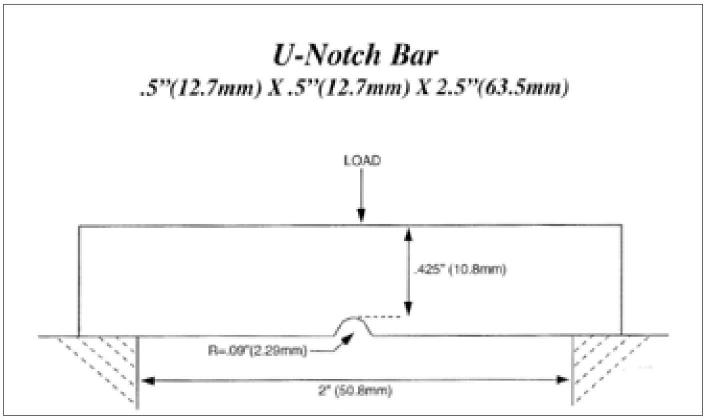


Figure 1

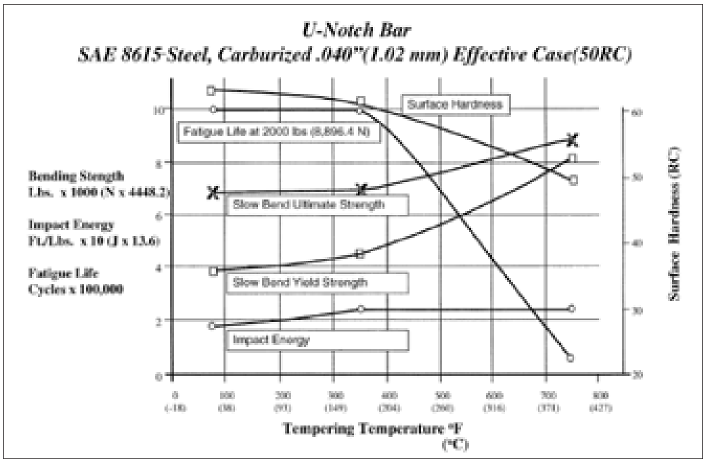


Figure 2

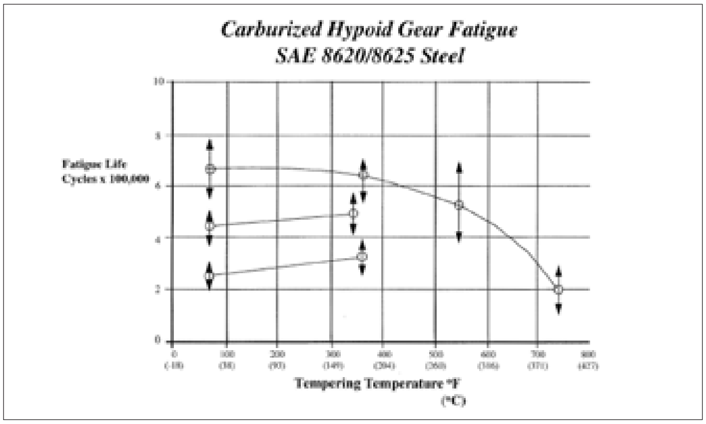
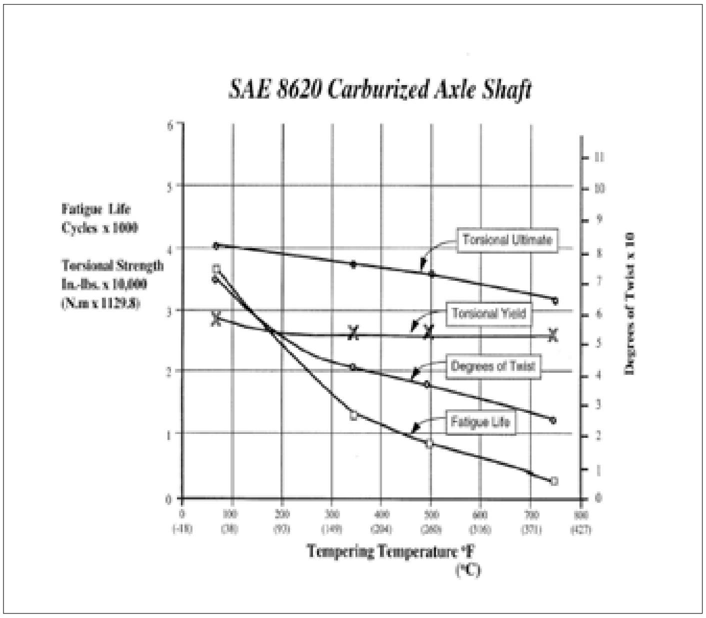


Figure 3



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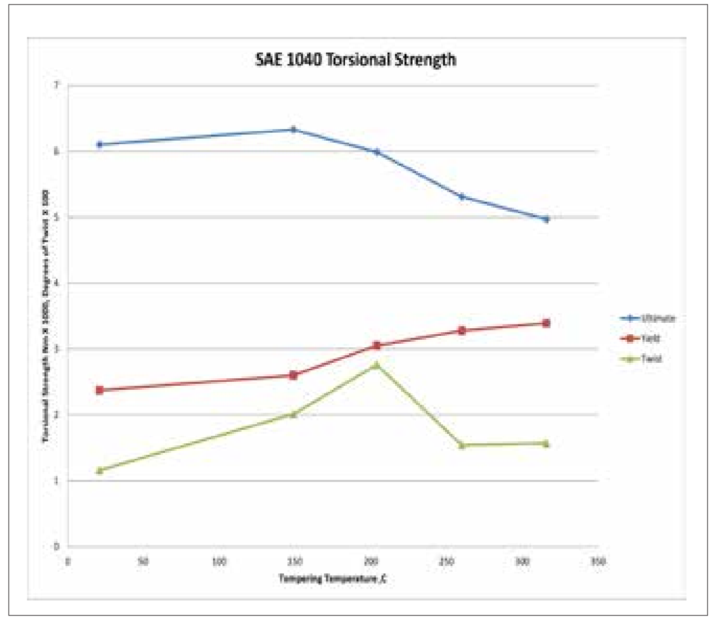

Figure 5

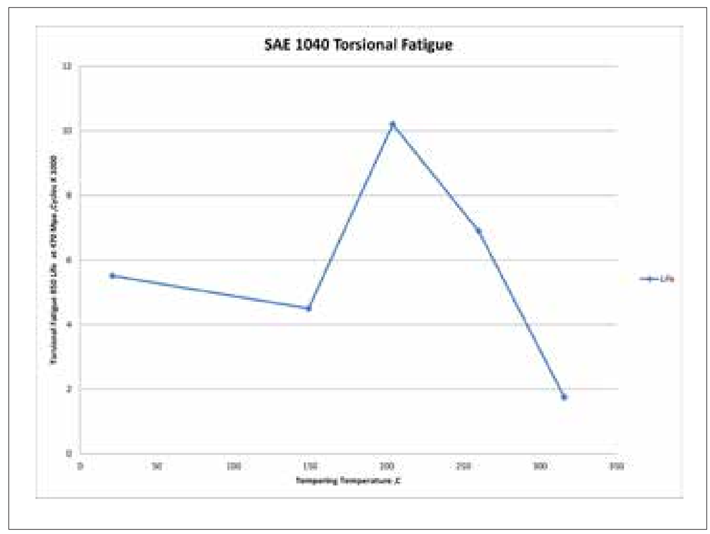

Figure 6

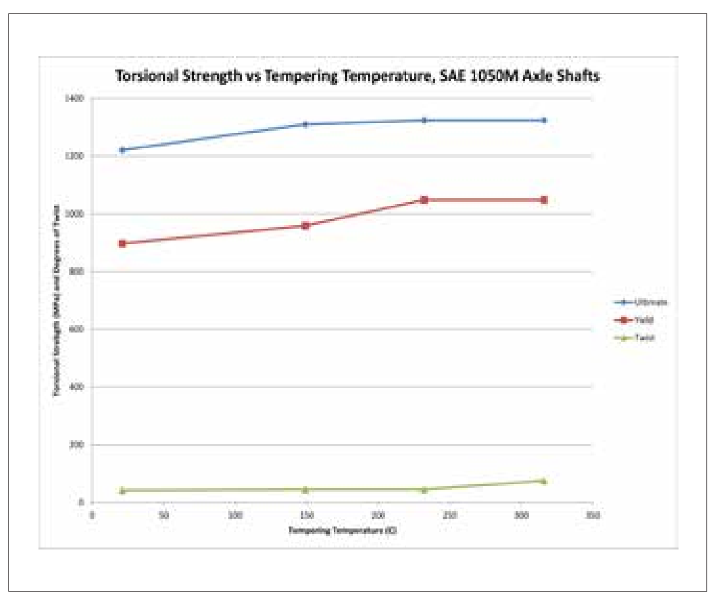

Figure 7

of carburized 8615 steel. The U-Notch bar simulates the root radius of a gear. Data is provided in Figure 2 for no temper vs. 350°F/177°C and 750°F/399° C. The upper temperature was of interest because, at the time, some drag racers were using this to allow carburized hypoid gears to survive. Longevity was not a concern as the gears would be changed after the event.

As expected, hardness decreased slightly with the lower temperature and more significantly with the higher temperature. The bending ultimate and yield strength increased slightly with the lower temperature and significantly with the higher temperature. However, the impact energy absorption increased only slightly with the lower temperature and remained the same at the higher temperature. This is likely because the yield and ultimate strength became closer, reducing the amount of plasticity. The fatigue life remained the same for the untempered condition and the lower tempering temperature but decreased significantly at the higher temperature. The data shows there is little difference in bending properties for the untempered condition vs. the low temperature temper. The higher temperature temper does provide an increase in bending strength but not in energy absorption.

Figure 3 shows bending fatigue data for actual hypoid gear sets vs. tempering temperature. The upper curve shows a slight decrease in fatigue life for the 350°F/177°C condition vs. the no temper condition. Again, the life at the high temperature condition is significantly reduced. Two additional tests are also shown, and there is a slight increase in life for the 350°F/177°C condition vs. the untempered condition, which is simply normal variation. The life for parts tempered at 350°F/177°C will be approximately the same as untempered parts, but once the tempering temperature exceeds that, the life will decrease.

CARBURIZED SHAFTS LOADED IN TORSION

Figure 4 shows torsional data for carburized axle shafts tempered at different temperatures. Shown is the no temper condition, 350F°/177°C, 500°F/260°C, and 750°F/399°C. The torsional ultimate and yield strength decrease gradually as the tempering temperature increases. The yield strength was determined using the Johnson Elastic Limit or JEL defined by a 50 percent change in slope. The ductility or degrees of twist decreased more rapidly with temperature, which is counterintuitive. The torsional fatigue life decreases sig-

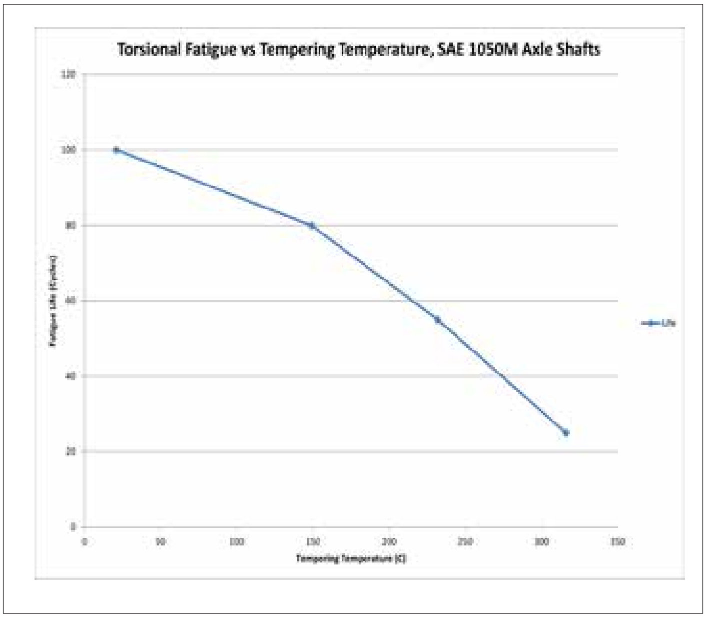

Figure 8

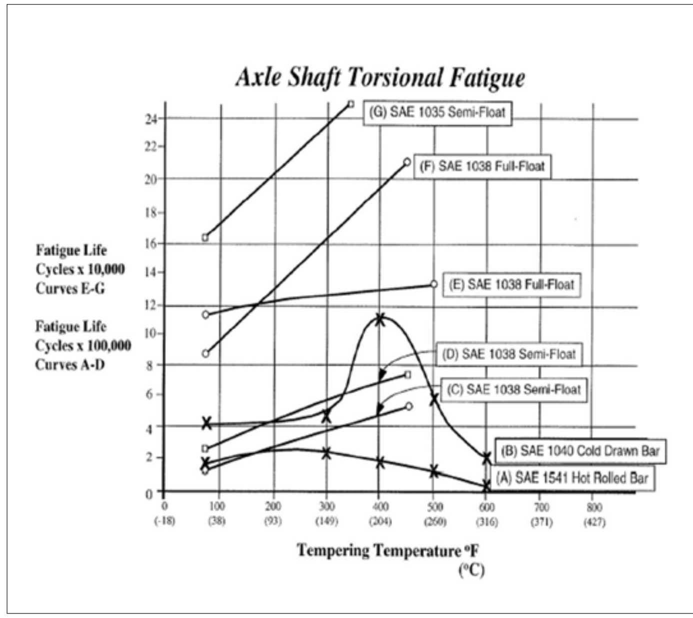

Figure 11

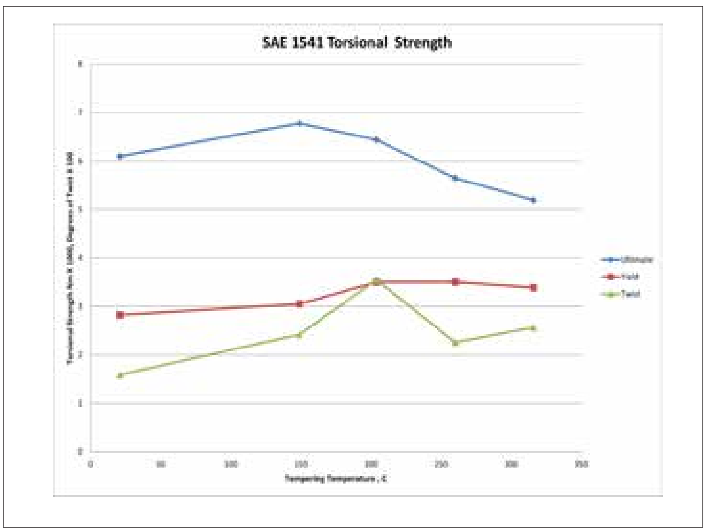

Figure 9

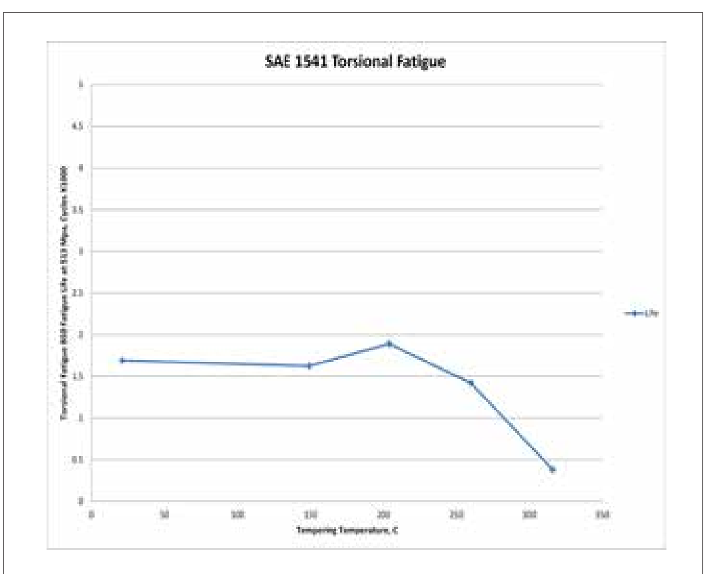

Figure 10

nificantly as the tempering temperature increases. The untempered condition provides the highest mechanical properties and fatigue life.

INDUCTION HARDENED SHAFTS LOADED IN TORSION

Figure 5 shows the torsional data for induction hardened cold drawn SAE 1040 steel double splined test shafts tempered at different temperatures. The torsional ultimate strength is about the same in the untempered and 300°F/149°C tempered condition and gradually decreases as the tempering temperature rises. The torsional yield strength is very low in the untempered condition and gradually increases with increasing tempering temperature. The ratio of torsional yield to ultimate strength starts at 0.38 with no temper and gradually increases to 0.68 at 600°F/316°C. The degrees of twist or ductility gradually increases with increasing tempering temperature and reaches a maximum at 400°F/204°C and then decreases with increasing temperature. It is important to note this increase in ductility does not always occur. It is present in some tests and not others with the same material.

The torsional fatigue life in Figure 6 is about the same in the untempered and 300°F/149°tempered condition and then rises significantly at 400°F/204°C. Above that temperature, the life decreases rapidly. There is usually an increase in torsional fatigue life with tempering on 1038 or 1040 steel, but it does not always occur at the same temperature. Sometimes it may be at 350°F/177°C or it may not occur at all.

Figure 7 shows the torsional data for induction hardened SAE 1050M semi-float induction hardened axle shafts. There is a slight increase in torsional ultimate and yield strength with increasing tempering temperature. Very little increase in degrees of twist was present. In other tests on this same part, an increase in torsional ductility was present at 600°F/316°C.

The effect of tempering on the torsional fatigue life of 1050M shafts is shown in Figure 8, and it is different than the 1040 shafts. Any tempering temperature will reduce the torsional fatigue life of 1050M shafts. However, because of the tendency to crack after induction hardening tempering can't be eliminated. However, a lower temperature can be used.

Figure 9 shows the torsional data for induction hardened 1541 double splined test shafts. The torsional ultimate, yield, and degrees of twist behavior is similar to the 1040. The torsional ultimate strength

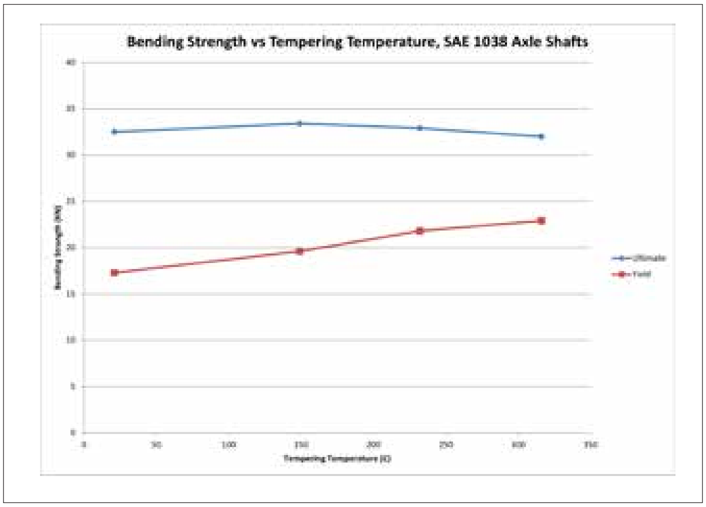

Figure 12

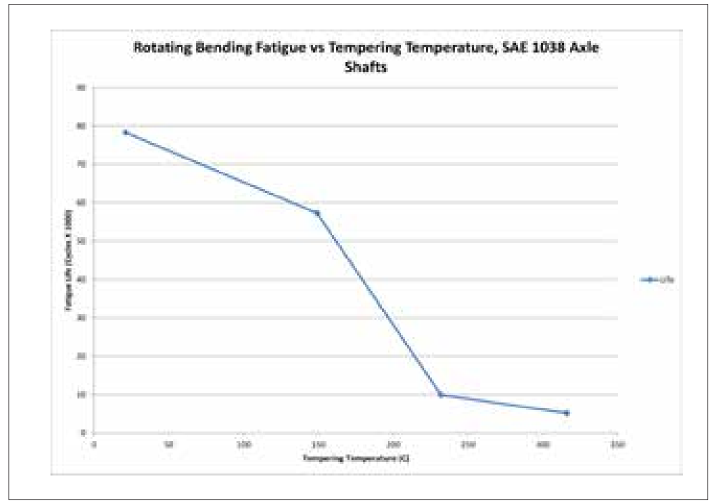

Figure 13

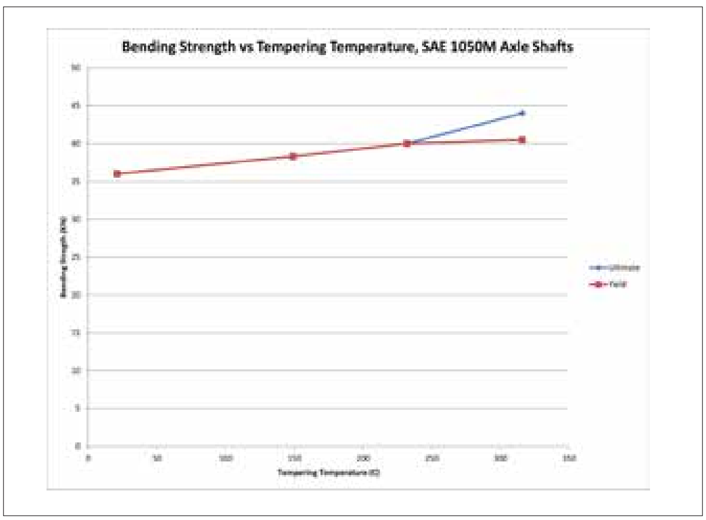

Figure 14

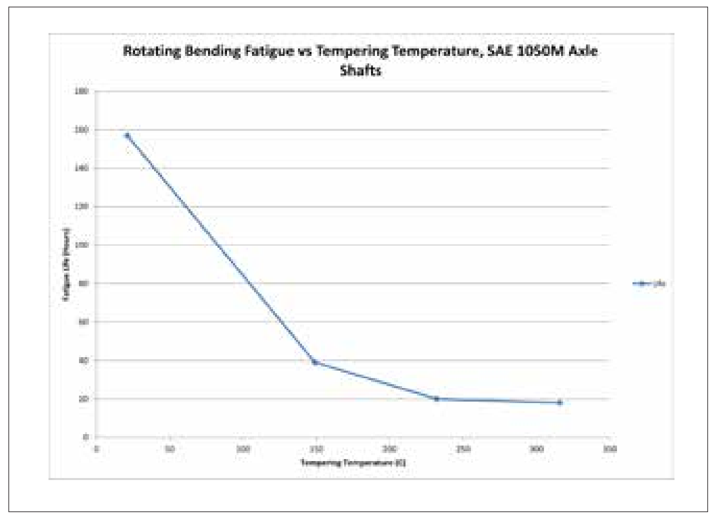

Figure 15

is maximum at 302°F/150°C. The ratio of yield to ultimate starts off low and increases with increasing tempering temperature. The ductility or degrees of twist increases to a maximum at about 393°F/200°C much the same as the 1040 grade.

Figure 10 shows the torsional fatigue life for the 1541 test shafts vs. tempering temperature. The life is relatively constant up to 400°F/204°C and decreases above that.

Figure 11 shows the effect of tempering temperature for several induction hardened shafts on torsional fatigue life. For the 1035, 1038, and 1040 steel grades, the torsional fatigue life increases with tempering temperature and reaches a maximum at about 400°F/204°C. However, the 1541 shaft has a decrease in torsional fatigue life above 300°F/149°C. The 1035, 1038, and 1040 steels had an effective case depth to 40 HRC at about 12 percent of the diameter due to their limited hardenability. The 1541 shaft had a deeper effective case depth at about 23 percent of the diameter.

INDUCTION HARDENED SHAFTS LOADED IN BENDING

Figure 12 shows the bending strength for an induction hardened 1038 semi float axle shaft. The bending ultimate strength is relatively constant with increasing tempering temperatures. However, bending yield strength does increase with increasing tempering temperature. The ratio of yield to ultimate increases from 0.53 to 0.69 from the no temper condition to the highest tempering temperature. Because of this mechanical straightening would be best done prior to tempering.

Figure 13 shows the rotating bending fatigue life for the same shaft. The life decreases from the no temper condition to the 350°F/177°C condition, and above that temperature, the life decreases rapidly. This is a significant change from the torsional data. Figure 14 shows an induction hardened 1050M semi float axle shaft also tested in bending. The bending ultimate strength increases slightly with increasing tempering temperature up to 450°F/232°C. Final fracture occurs with no yield. Above this temperature, the increase in strength is a little more rapid and a definable yield begins to occur.

Figure 15 shows the rotating bending fatigue life vs. tempering temperature for the same shaft. The rotating bending fatigue life drops significantly at the 350°F/177°C tempering temperature. However, tempering can't be eliminated because of the risk of cracking, especially with this higher carbon grade of steel. This would be a case where the lower 280°F/138°C tempering temperature would be useful.

INDUCTION HARDENED SPINDLES LOADED IN BENDING

Figure 16 shows bending impact data for a 15B35 induction hardened U-Notch test bar used to simulate a spindle. The bending impact strength is constant up to 350°F/177°C and then decreases slightly up to 800°F/427°C. The impact bending yield strength increases significantly up to 500°F/260°C then decreases up to 800°F/427°C. The impact energy absorption is constant up to 500°F/260°C then begins to increase above that.

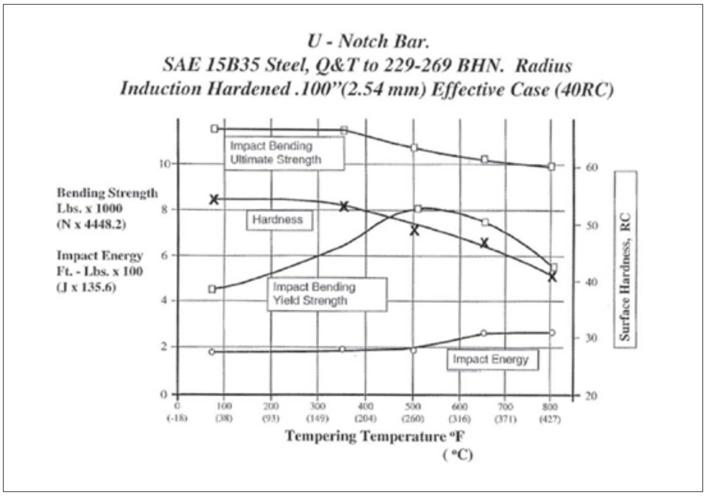

Figure 16

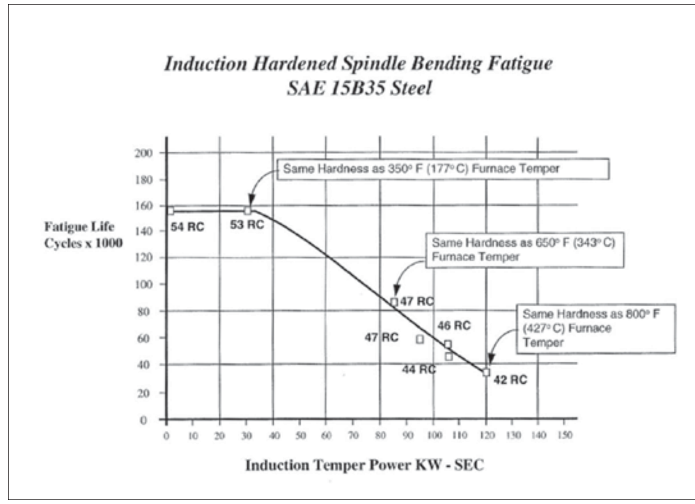

Figure 17

Figure 17 shows the bending fatigue life for the actual 15B35 spindle. Induction tempering was used, and the relationship to the U-Notch bar furnace tempering hardness is shown. The bending fatigue life is constant up to 350°F/177°C but then decreases rapidly above that.

REFERENCES

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ABOUT THE AUTHOR

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