ENHANCED STEEL PERFORMANCE DURING VACUUM CARBURIZING OF GEARS

There are many benefits that can be gained from vacuum carburizing, but material selection is critical to producing a consistently high-quality carburized gear.

MANY REFERENCES COVER THE HISTORY AND DEVELOPMENT of low-pressure carburizing, colloquially known as vacuum carburizing, so we’ll start our discussion with the motivations of gear manufacturers in choosing this process [1, 2]. The vacuum carburizing benefits commonly cited are the elimination of intergranular oxidation (IGO) for increased fatigue life, minimization/increased consistency in distortion response, elimination of an oil quench, energy efficient furnaces, better gas-quenching flexibility, and reduced carburizing times due to high-temperature furnace capabilities. Of this long list of potential benefits, we will discuss three key areas: high-temperature carburizing, fatigue performance (eliminated IGO), and response to high pressure gas quenching (HPGQ). Understanding how to optimize each of these conditions during vacuum carburizing can influence the proper alloy design and heat-treat methodology.

GRAIN COARSENING RESISTANCE

Vacuum carburizing furnaces are capable of operating at higher carburizing temperatures than traditional gas carburizing furnaces. An exponential relationship between carburizing temperature and case depth exists, shown in Figure 1, allowing for reduced cycle times. Figure 1 shows that, for an equivalent case depth, you can achieve a 43 percent or 55 percent reduction in carburizing time by increasing the carburizing temperature by 50°C or 70°C, respectively. However, most steels and processing schemes are not capable of maintaining a fine grain size at elevated carburizing temperatures.

A fine grain size is required to ensure optimal part performance after carburizing. Steel composition and prior processing can be used to increase the temperature at which austenite grain coarsening begins. The higher this temperature, the higher the carburizing temperature that can be used — thus capturing an increased benefit of reduced carburizing cycle time. Figure 2 shows composition and processing modifications to a traditional 5120 steel can increase the grain coarsening temperature from 980°C to above 1,050°C.

Figure 1: Plot showing carburizing time (hours) versus case depth (mm) for three different carburizing temperatures. Arrows are highlighting that, for an equivalent case depth, you can get a significant reduction in carburizing time by increasing the carburizing temperature.

Figure 2: Plot illustrating the relationships developed between steel composition and process variables with the maximum fine grain carburizing temperature for a series of modified 5120 steels.

FATIGUE IMPROVEMENT

Fatigue testing is a primary performance measurement for carburized applications. Attainment of case and core characteristics is paramount to developing the necessary fatigue properties for a part.

Vacuum carburizing results in the elimination of intergranular oxidation and other related near-surface effects prevalent in gas carburizing. Four-point bending fatigue testing has been used to simulate gear root bending fatigue through the use of a notched test sample [3, 4]. These fatigue results can be used to compare various grades and process conditions. Figure 3 highlights the improvement in fatigue life runout when IGO is removed or prevented. The middle pair of conditions shows a 283 MPa increase in runout stress for identically heat-treated 8620 before and after mechanical removal of the IGO produced in traditional gas carburizing. The left and right side pairs show the comparison in runout stress between gas carburized and vacuum carburized conditions for 5120 and 8620, respectively. These two pairs show a similar boost in runout stress (239 MPa for 5120, 311 MPa for 8620) attributed primarily to the prevention of IGO formation during vacuum carburizing.

Figure 3: Graph showing the improvement in fatigue life runout when IGO is removed or prevented.

Figure 4: Bar chart illustrating the improvement in fatigue life runout for various grades and process conditions.

ROBUST HPGQ RESPONSE

Some early adopters of vacuum carburizing and HPGQ soon found the grades traditionally used in their gas carburizing process did not have sufficient hardenability to meet properties with a less severe gas
quench. Because of this reason, many existing and proposed new grades of steel were analyzed for their ability to produce robust core hardness results in an HPGQ process. A designed experiment that varied composition (a 5120Mod and three experimental grades), sample size (0.75-inch, 1.5-inch diameter cylinders), HPGQ pressure (10, 15 bar nitrogen), and location with a furnace load (top, middle, bottom) showed the ability to link standard Jominy data to the expected core hardness given the cooling rate produced at the core of a gear [5]. Figure 4 shows the results of this study, plotting cooling rate (as calculated from measured temperature data from embedded thermocouples) versus the hardness immediately next to the embedded thermocouple. The plotted points represent the measured data, while the solid lines are the associated Jominy data for each grade plotted against cooling rates for each J-position.

CONCLUSIONS
Vacuum carburizing is a technology that is gaining broad acceptance in the industry in Europe and North America. Significant value can be brought to vacuum-carburized applications through steel-grade selection, development, and testing. Today, available steels provide consistent hardenability for each application, robust material response to varying quench rates, high-temperature grain coarsening resistance, and a cost-effective, lean alloy design. All of these aspects can help gear heat-treaters achieve the many cost reduction and performance enhancement opportunities available with vacuum carburizing heat-treating technology.

REFERENCES:

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