VACUUM CARBONITRIDING PROVIDES
EXACT, PREDICTABLE CASE DEPTHS

Making die cutting punches from 1018 low carbon steel, 52100 alloy steel, D1 and D2 tool steels, and specialty alloys requires flexibility and precise heat treat control.

Ken Specialties, Inc. of Wood Dale, IL found that processing die-cutting geometry with precision tolerances required a more responsive heat treating operation. The process also had to be environmentally friendly, part-to-part consistency had to be improved, and different materials had to be processed in a single furnace. Finally, they had to meet a one-day delivery commitment to the customer. Originally, a salt bath process was being used for carbonitriding. Outside processors for hardening tool steels and specialty materials were not meeting the quick delivery and high quality required. Inconsistent part hardness, shortened punch life and dimensional changes resulted in high scrap rates. Consequently, a number of alternative furnace technologies were investigated, including gas atmosphere hardening and carbonitriding in batch integral oil quench furnaces, fluidized bed equipment and vacuum.

Superiority of Vacuum

After several discussions, a “wish list” of features was compiled. The system requirements included oil and gas quenching capabilities, a pitless furnace, automated controls and a unit sized to fit into the existing heat treating area. The system needed to be flexible enough to handle different types of steel using other heat treating processes as well. A furnace made by C.I. Hayes, Inc. of Cranston, RI met all these requirements. By adding sequencing automation, as well as process automation, the learning curve for the equipment was reduced while being able to process load after load with consistency.

Carbonitriding in a vacuum furnace is a two-phase operation. The first (or boost) phase supplies carbon and nitrogen to the workpiece surface, causing these materials to be absorbed. The second (or diffusion) phase consists of diffusing the carbon and nitrogen to obtain the proper case depth and surface concentrations. Vacuum carbonitriding is a non-equilibrium, boost/diffusion type process in which the workpiece is heated to austenitizing temperature in a rough vacuum; carbonitrided in a partial pressure of hydrocarbon and ammonia gases; diffused in a rough vacuum; and quenched in either oil or gas.

The primary benefit of vacuum carbonitriding is the precise control over carbon and nitrogen absorption and diffusion, establishing the rate of penetration. This results in exact and predictable case depths, surface carbon contents and metallurgical properties. The variables that influence and control the process are time, temperature and carbon potential. Vacuum allows the selection of precise levels of carbon and nitrogen available to the process. This is done by varying gas flow, gas pressure and hydrocarbon concentration in the gas mixture. Vacuum avoids such detrimental influences as non-equilibrium gas states, temperature differentials and surface abnormalities present with other technologies.

Vacuum carbonitriding allows absorption of carbon and nitrogen to the limits of their solubility in austenite. This is "pure carbonitriding" because a 100% carbon and nitrogen potential is always generated at the surface, and the austenite is always saturated. The saturation level is always constant at any given temperature, creating an accurate starting point for case development during the diffusion cycle. In atmosphere carbonitriding the practical, usable carbon and nitrogen potentials of the atmosphere provide only partial saturation.

In vacuum carbonitriding the steel itself controls the process. Specific case depths and carbon concentrations can be determined by computer and programmed into the unit. The advantages of increased hardening include the use of less drastic quenches for a given part size, the ability to harden larger diameter pieces, and the use of low carbon steels, such as 1018 instead of alloy steels. Typical vacuum carbonitrided case depths vary from a few tenths to about 0.030" depending on application. The process is usually carried out in the temperature range of 1475° to 1650° F, resulting in tight case depth uniformity.

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Benefits of Pulse/Pump Technology

Pulse/pump carbonitriding results in uniform case depth and minimal gas consumption. The first (or pulse) stage consists of repeatedly accumulating a small charge of carbonitriding gas in a tank external to the furnace at either a fixed or variable positive pressure. The charge is released, or pulsed, into the heating chamber through an injector, transferring the kinetic energy of the gas molecules to the workload. The pulsing is repeated until a predetermined partial pressure setpoint is achieved, and, after a predetermined exposure period to the workload surfaces, the gas is evacuated.

The cycle continues, alternately pulsing and pumping, for the duration of the boost stage. Timers control the gas duration during the boost stage so that diffusion of carbon away from the surface takes place. The principle operating variables for this method are accumulator pressure, release frequency, evacuation time and carbonitriding gas partial pressure. To be effective the carbonitriding gas must be supplied to all areas of the workload, compensating for surface area, geometry and mass effect.

The advantage of the pulse/pump method is that gas circulation is effective at low partial pressures using relatively simple components. Another benefit for Ken Specialties in over five years of using the Hayes pulse/pump system is that major components, such as the heating chamber insulation, heating elements, pulse injector, and hearth rails and rollers, have not had to be replaced.

Vacuum furnaces use a water-cooled metallic shell and don't discharge heat into the room. With graphite insulation, and the all-graphite heating zone, there is enough carbon present to allow a thermo-chemical reaction to occur. As the chamber is heated, any oxygen or water vapor that may be present is rendered harmless to the work being processed. The vacuum-tight vessel makes it unnecessary to use low vacuum pressures. Conventional vacuum pumps are used to evacuate the furnace to pressures less than 0.01 kPa (0.1 torr), where there is little oxygen or water vapor present. Because the insulation and elements are graphite, there is no effect on them from the carbonitriding medium.

Oil Quenching

There is also a difference in the way parts are quenched in a vacuum furnace. In an atmosphere furnace, the usual direction of oil flow is upward through the workload. Because the surface of the oil is exposed to a gaseous cover, it is desirable to minimize any entrapment of gases in the quenching medium. Trapped gases react physically with the steel by forming gas pockets and bubbles that inhibit the quenching rate and increase distortion.

Subjecting liquids to vacuum pressures will cause entrapped nitrogen or water vapor to "boil out" rapidly. In a vacuum furnace that has been pumped
down to 0.1 kPa (1 torr) or less, the quench oil will be completely evacuated of any entrapped gases prior to quenching each workload. Since the flow of oil in the quench tank of a vacuum furnace is downward, the composition of the gas bubbles formed during the quench under vacuum is entirely different from the composition of those formed under an atmosphere.

For any given quench oil, the quench rate under vacuum conditions is faster than that achieved under atmosphere. This is because there are fewer gas bubbles in the oil under vacuum. Also, the composition of the gas bubbles is different, allowing the vapor layer to be removed more easily and uniformly from the surface of the part being quenched. This invariably results in improved distortion and dimensional control. Vacuum furnaces also produce work that is absolutely clean and free of scale or surface contamination.

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