Welding Different Gear Materials

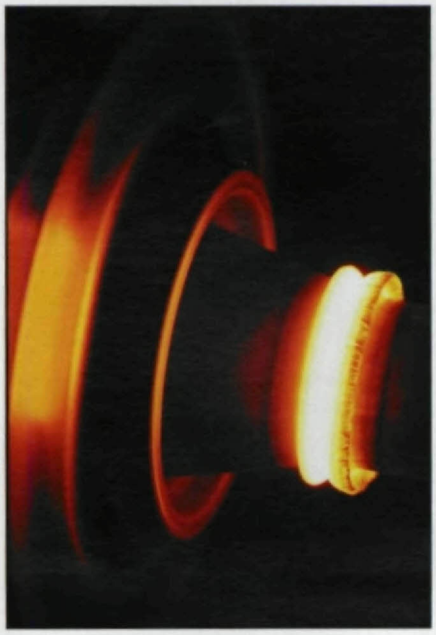
Friction welding has been thought of as a solution for customers with lots of volume to be welded and lots of capital investment. Industry opinions are changing, though, and it's becoming an economic option for small-volume batches.

The process has been around for awhile but has never been as popular as other conventional means of welding. Unlike traditional welding, friction welding can join both similar and dissimilar materials with different mechanical and physical properties through rotational forces and hydraulic pressure without flux or filler material. Good candidate materials for these combinations are carbon and alloy steels.

Among the gear industry applications are bi-metallic propeller shafts for the marine industry, splined axle shafts and flanged gear blanks.

In addition, friction welding takes place in a narrow, heat-affected zone, so it has minimal effect on adjacent machine or heat treat characteristics, says Joel Donohue, general manager of American Friction Welding.

The job shop, located in Brookfield, WI, has offered this service for years, mostly on hydraulics, pump shafts, electric motor shafts, drills, and hand tools, as well as automotive and construction equipment.



An axle is being friction welded to a standardized hub-like end. Photo courtesy of American Friction Welding, Inc.

Whatever the product is, once it arrives at American Friction Welding, the welding process starts with the product's axis of symmetry. It's easiest when the components have a natural axis of symmetry. If a part is not already equipped with this, then engineers develop the tooling to create one.

After the axis of symmetry is determined, weld parameters are developed which include rpm, axial load, time frame, and amount of axial shortening. After developing these parameters, parts are then tested in a situation that mimics its actual performance. Once those parameters are established and proven, they're loaded into the machine's controller. Then they begin the process of loading parameters and feeding components before commencing production. The machine controller monitors those set parameters and their limitations throughout the production run. If anything falls outside the parameters, the machine sends out an alert.

One workpiece is held in a rotating spindle and the other is held in a stationary clamp. Operators control the speed of the motor-driven workpiece. Then, an axial load is applied to the components being welded. Interfaces of the two components rub together, resulting in heat.

This is maintained until a predetermined amount of time or axial shortening occurs. At this point, a braking force is applied and the axial load is increased in the final forge phase. This force is held for a pre-set amount of time after the rotation stops.

Many times, a post-weld test is done on a sampling basis as the final step to check for torsional, bend or hardness properties of the heat affected zone. In addition, ultrasonic inspection is used to evaluate the weld integrity.

All of this, excluding the post run testing, takes from five seconds to several minutes. When factoring in the testing, the initial weld development process can last from a few hours to a few weeks, depending on part size, shape and configuration.

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As far as capabilities, American Friction Welding has eight direct-drive friction welding machines ranging from four to 125 tons, which can weld solid diameters from 1/8"–4 1/4".

"One machine has part orientation. Its spindle has an end coder on the spindle that keeps track of where the spindle starts and stops," says Donohue "The advantage of this feature is that the components can have uniquely machined features with a relationship to one another after welding within +/–1.5°." This kind of control is a major benefit to the direct-drive welding process.

However, there's another type of friction welding called inertia welding. Manufacturing Technology Inc. in South Bend, IN, does both and points out distinctive aspects of each approach.

Inertia welding uses flywheels bolted to a spindle chuck. The spindle accelerates to a pre-determined speed, its motor is disengaged and the workpieces are forced together under forge force. As the spindle speed slows, the kinetic energy stored in the rotating mass dissipates as heat through friction at the weld interface. The welding force continues to push the two components together for a short period of time after the rotation ceases.

Though it offers the operator less control, inertia welding generally has faster cycle times, a narrower heat-affected zone and fewer weld variables (rpm and pressure) and does not require clutches and brakes, says Kevin Grewe, sales engineer for MTI Welding.

"For gears, there's not a definite method that's better than the other. Sometimes there's the need to orientate one gear onto another and, in that case, the direct drive friction welding is best," he says. "We do slightly more inertia welding, mainly because automakers want such high cycle times."

Friction welding, whether done by inertia or direct drive, is not a solution for every company or application. Many times, the component configuration and material type are good indicators of whether the process is a good fit. Generally, free machining and resulfurized materials, which contain high levels of lead and sulfur, may have adverse effects on the joint, says Donohue.

For Kuhn Knight Manufacturing Inc. of Brodhead, WI, the friction welding process was a perfect fit. Hugh Hosely, a buyer for the company, hired American Friction Welding several years ago to friction weld Kuhn's plug assembly products.

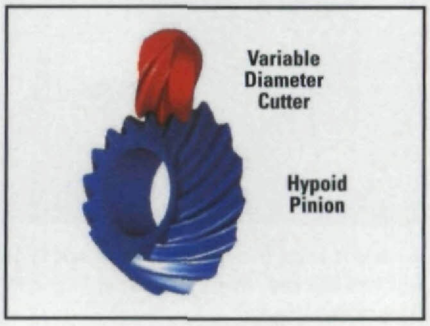
"We've been very happy with the service," he says, "it's inexpensive and produces a better product because two pieces become one. Also, with a traditional weld, they're only held together by a ring of weld, and this is far superior."

No Pitch Cones, No Face Cutters = Greater Gear Freedom

David Dooner wants more freedom for designers and manufacturers of spiral bevel and hypoid gears. He wants to give it to them by removing the gears' restrictions on face width, spiral angle and number of teeth.

He also wants them to be free to specify those gears with the same procedure they use to specify cylindrical gears.

And Dooner has a way to achieve this freedom: Eliminate pitch cones and



face cutters from the design and manufacture of spiral bevels and hypoids.

Dooner has been working on this way since the late 1980s, when he was a graduate student at the University of Florida, Gainesville. Studying for his doctorate, Dooner started to think about unifying the design and manufacture of different type of gears, using their kinematic structure to create a single framework.

He discussed his idea with his doctoral advisor, Ali Seireg, and it became part of his doctoral thesis. It also provided the foundation of his method for spiral bevels and hypoids.

After receiving his doctorate, Dooner continued to work on the method, collaborating with Seireg until Seireg's death in September. Today, Dooner is an associate professor in the mechanical engineering department at the University of Puerto Rico-Mayagüez.

To this point, his method remains theoretical—"It hasn't been developed."

Dooner says it hasn't been because: "First, the mathematical relationships are not immediate." and "Second, there is a well-established art, with an enormous base."

He adds that most people are focused on improving the existing method—"There's been little effort to developing new ways."

Dooner, however, has been focused on getting rid of pitch cones and face cutters to create a new way.

He explains: Pitch cones are a design tool for spiral bevel and hypoid gears. While helpful, the cones restrict the face widths of those gears.

With Dooner's way, the gears would be designed using mathematical formulas that compare the spiral bevels and hypoids with their theoretical ideals. That contrasts with today's practice of comparing them with the ideals that can be obtained through manufacture.

Dooner says using the theoretical ideals gets rid of the restrictions on spiral bevels and hypoids' spiral angle and number of teeth and may get rid of their limit pressure angles.

During manufacture, face cutters of spiral bevels and hypoids create teeth of increasing thickness as they move across a gear's face.

Dooner's cutters, though, would be like variable diameter gears with cutting teeth. They'd cut like variable diameter hobs, so they'd compensate for varying tooth thickness. The compensating would remove restrictions on face width and spiral angle. Without face cutters, number of teeth wouldn't be restricted, either.

Dooner says cutting spiral bevels and hypoids would become like hobbing cylindrical gears, so specifying them could become like specifying cylindrical gears. Tooth profile, pressure angle, spiral or helix angle, face width—they could all be used to design and manufacture spiral bevels and hypoids.

According to Dooner, the cutters could even be used to manufacture cylindrical gears. Different cutters would still be needed to manufacture different gears—coarser pitch cutters for coarser pitch gears, finer for finer, bigger cutters for bigger gears, smaller for smaller—but the cutters would be the same type and could be used in the same type of machine.

Dooner says his machine and cutters would streamline a gear manufacturer's machine tool facilities while making them more flexible in the types of gears they could create.

According to Dooner, his method would provide several other benefits. First, gear manufacturers would be able to create lead, crown and profile relief in their spiral bevel and hypoid gear sets at the same time they're cutting them.

Second, they might not need to lap, burnish or polish the sets. Dooner says if lapping, burnishing or polishing wasn't needed, gears and pinions would be interchangeable. If one broke, a gear manufacturer could replace just that member of a hypoid or spiral bevel gear set; he wouldn't have to make an entirely new set.

Third, his method would offer new alternatives in gears through its greater design flexibility. For example, spur hypoidal gears—not possible in today's manufacture—would be possible. Dooner describes spur hypoidals as non-intersecting, non-parallel gears whose teeth go into and come out of mesh all at once.

Moreover, Dooner simulated their manufacture and saw his method could even make spur hypoidals more efficient by reducing their sliding contact.

Spur hypoidal gears could be used in rear axles of automobiles.

Before benefits, there'd have to be development and testing. Both are possible, though. Dooner's work is at a point where a machine and set of cutting tools could be developed for testing. He doesn't know how much money it would take to create them, but he doubts it would be an unusual amount: "How much would it take to develop an existing machine?" ○

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