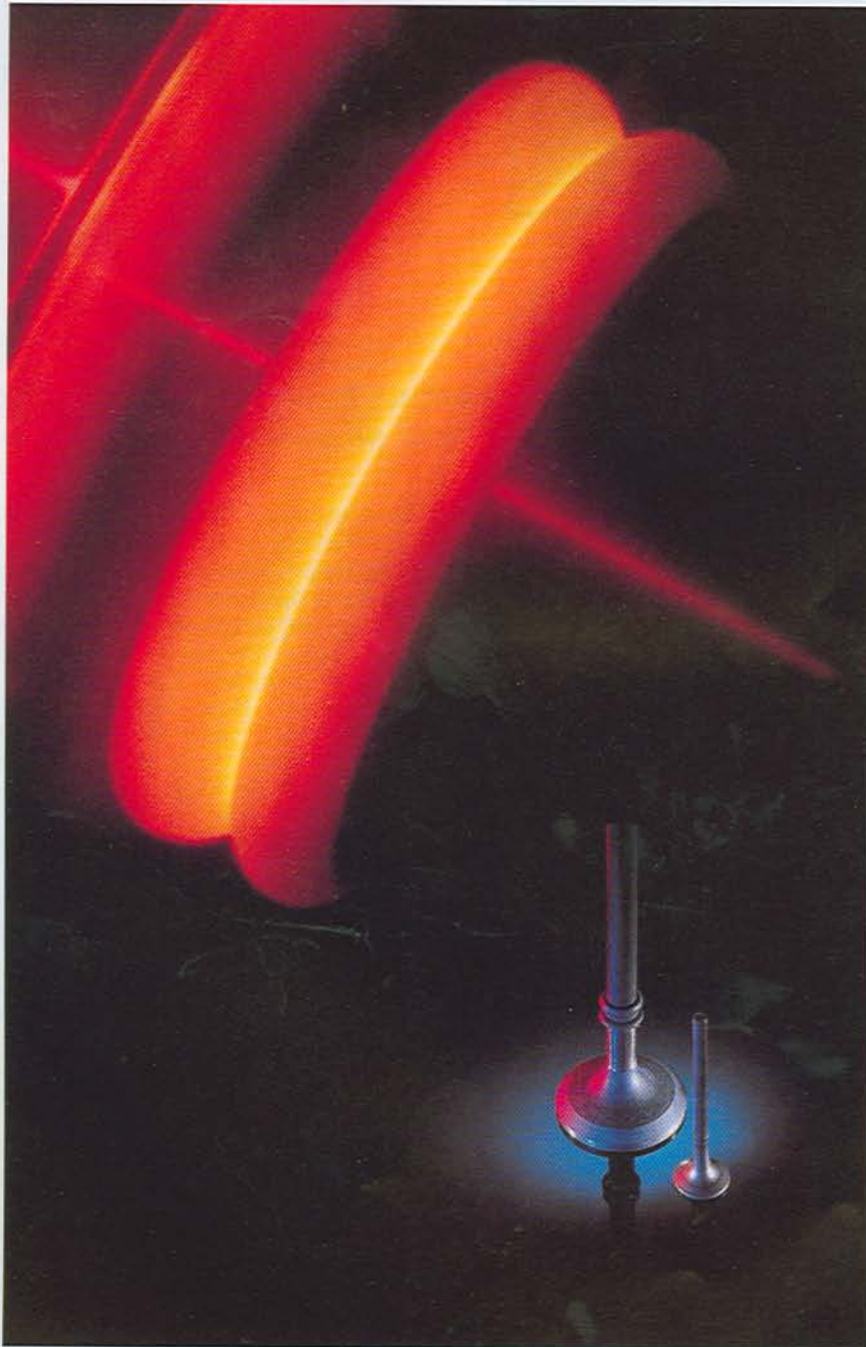




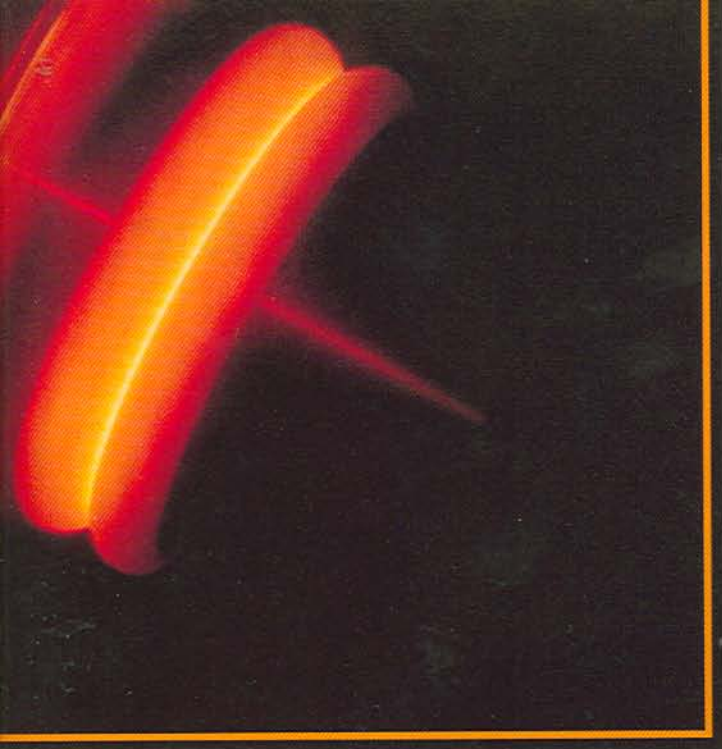
Manufacturing Technology, Inc.

What Industry Needs to Know About Friction Welding



BY D. E. SPINDLER

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Friction welding is a fast, effective way to join a wide variety of production parts.

What Industry Needs to Know about Friction Welding

BY D. E. SPINDLER

This technological orphan continues to attract attention from engineers in the automotive, off-highway, aircraft, and oil industries

Despite the fact that friction welding has been around for more than 50 years, it is a process that has received little support from the engineering governing bodies. To make matters worse, many technical people either do not know anything about friction welding or feel that it is an unproven new technology. Those who are familiar with the technology seldom agree 100% with any technical data necessary for the formation of useful industrial specifications.

The intent of this article is simply to try to give an overview and to provide information which would be useful for anyone unfamiliar with the friction welding process.

First, here is the definition of friction welding published in the AWS C6.1-89 Standard, *Recommended Practices for Friction Welding*.

"Friction welding is a solid-state joining process that produces coalescence of materials under compressive force contact of workpieces rotating or moving relative to one another to produce heat and plastically displace material from the faying surfaces. Under normal conditions, the faying surfaces do not melt. Filler metal, flux, and shielding gas are not required with this process."

Friction welding in production is an automatic process essentially for circular components. The basic steps in friction welding are illustrated in Fig. 1. First, one workpiece is rotated and the other is held stationary — Fig. 1A.

The two workpieces are brought together as an axial compressive force (friction welding force) is applied — Fig. 1B. Rubbing of the faying surfaces heats the workpiece locally and upsetting (change in length) begins Fig. 1C. The

process is complete when rotation of the one workpiece stops and upsetting ceases — Fig. 1D.

The weld produced is characterized by the absence of a fusion zone, the narrow heat-affected zone, and the presence of plastically deformed material around the weld (flash). Weld quality is dependent upon the proper selection of the material, joint design, welding variables, and post weld processes. Acceptable welds can be made in many materials using a wide range of weld parameters, *i.e.*, speed, force, and time.

Yes, it works — simply and efficiently with most engineering materials. The friction welding processes are divided and named by motion and drive (or energy source). One is direct-drive friction welding and the other is inertia friction welding.

What's the Difference between the Two Processes?

I had promised myself not to go into this and I will not answer any "fan" mail. However, the Features Editor of the *Welding Journal* asked me to elaborate. Again, as a definition, I will use the *AWS Recommended Practices for Friction Welding* definition:

In the direct-drive variation of friction welding, one of the workpieces is attached to a motor-driven unit, while the other is restrained from rotation. The motor-driven workpiece is rotated at a predetermined constant speed. The workpieces to be welded are moved together, and then a friction welding force is applied. Heat is generated as the faying surfaces (weld interface) rub together. This continues for a predetermined time, or until a preset amount of upset

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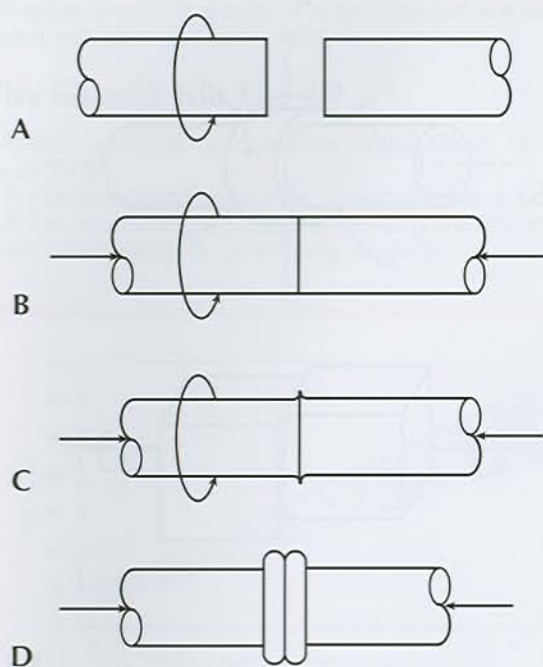


Fig. 1 — The basic steps in friction welding are as follows:
 A — One workpiece is rotated and the other is held stationary;
 B — the two workpieces are brought together as an axial force is applied; C — rubbing of the faying surfaces heats the workpiece locally and upsetting begins; D — the process is complete when rotation of the one workpiece stops and upsetting ceases.

takes place. The rotational driving force is discontinued, and the rotating workpiece is stopped by the application of a braking force. The friction welding force is maintained or increased for a predetermined time after rotation ceases (forge force). The relationship of direct-drive friction welding parameter characteristics is shown in Fig. 2.

In the inertia friction welding variation, one of the workpieces is connected to a flywheel, and the other is restrained from rotating. The flywheel is accelerated to a predetermined rotational speed, storing the required energy. The drive motor is disengaged and the workpieces are forced together by a friction welding force. This causes the faying surfaces to rub together under pressure. The kinetic energy stored in the rotating flywheel is dissipated as heat, through friction at the weld interface, as the flywheel speed decreases. An increase in friction welding force may be applied (forge force) before rotation stops. The forge force is maintained for a predetermined time after rotation ceases. The relationship of inertia friction welding parameter characteristics appears in Fig. 3.

Further modifications of friction welding include radial, orbital, angular reciprocating, linear reciprocating, friction welding, and friction surfacing. These processes are shown in Fig. 4A-D. Radial friction welding can be used to join tubular sections where it is undesirable to rotate either of the tubes, or collars to shafts and tubes. Orbital motion may be used to weld noncircular parts. In this application, neither piece rotates about its central axis. The orbital motion provides uniform tangential velocity over the total interface area. When motion ceases, the workpieces are aligned rapidly.

As each name implies, friction is created by various relative motions using either direct-drive motors or kinetic energy from a rotating flywheel.

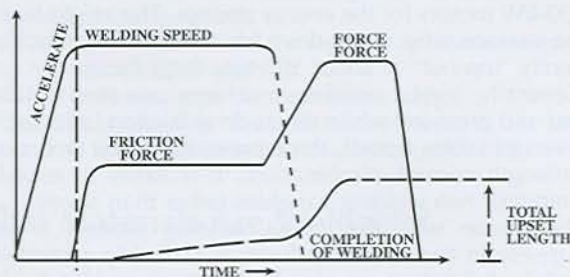


Fig. 2—The relationship of direct-drive friction welding parameter characteristics.

Both processes (inertia friction and direct-drive friction welding) produce excellent solid-state bonds. There are subtle differences or advantages of one process over the other. However, these advantages are not universal but depend upon the application (size, material combination, geometric consideration).

For instance, it is virtually impossible to achieve radial orientation on an inertia welding machine. It is also more difficult in inertia welding and requires complex controls to weld to a specific final overall parts length if the incoming parts are of larger length tolerances than the required final tolerance. A direct-drive friction welding machine can use a simple length control by measuring slide movement. In addition, inertia welding uses higher specific pressures for solid (bar) welds than direct-drive friction welding. This means that on a 100-ton machine, a direct-drive friction machine could weld up to 3.5 in. (89 mm) diameter while an equivalent inertia welding machine can weld only 2.75 in. (70 mm) diameter, based on the friction welding of medium carbon steel.

In tubular applications, both processes use about the same specific pressures. As such, they have the same capabilities.

Also, since direct-drive friction welding usually uses two lower friction pressures before applying the final forge pressure, tooling design can be lighter since welding torques are lower.

The Role of the Flywheel

The use of the flywheel as a capacitor allows inertia friction welding machines to discharge their energy over a shorter time. This will generally result in shorter weld times, less flash and narrower heat-affected zones.

Drive systems for large machines, 500 to 2000 tons, would consist of 700 to 3000 kW if direct-drive friction

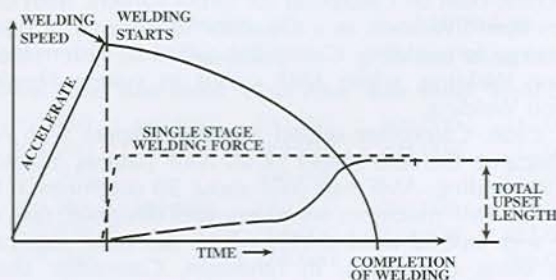


Fig. 3 — The relationship of inertia friction welding parameter characteristics.

welding machines were used. Inertia welding machines can supply the needed energy from the flywheel using only 100 or 200-kW motors for the energy storage. This might be one of the reasons why direct-drive friction welding machines presently "top out" at about 300 tons forge force.

Generally, inertia welding machines use two variables (speed and pressure) while direct-drive friction units use up to seven variables (speed, three pressures, three timers or a timer/length control combination). It is easier to establish and monitor two welding variables rather than seven.

The reason why the inertia welding process is used exclusively in the aircraft industry is probably a combination of the following:

- 1) Large 250-ton inertia welding machines were already available in 1968 when the aerospace industry needed them.
- 2) Ease of control and monitoring of the process.
- 3) Larger machines up to 2000 tons and above are not a technical (drive) problem.

This is not to say that direct-drive friction welding machines could not be used to come up with the same quality welds, but 25 years of an existing data base with the inertia welding process is difficult to overcome. Any buyer of friction welding equipment should select whatever machines and process are best suited for his own application and what is best for his company. There is too much sales "hype" in this business which is allowed to continue because many U.S. engineers and technicians have not even heard of friction welding in school. As such, they are unable to separate fact from fiction.

It seems that the least-popular motion machines receive the most space in technical magazines. To the best of my knowledge on a world-wide basis, there are only six linear friction welding machines; two rotary-oscillating units; two radial friction welding machines; and one orbital friction welding machine in use today. Of these, only two linear friction welding machines may be considered as working in a production environment. All the others are used in research and development.

In contrast, there are at least 2000 rotary machines throughout the world, welding everything from hand tools to aircraft engine components. Again, most of these machines (probably 99%) produce butt joints.

How Did It Start in the U.S.?

Historically, the three companies which started the modern friction welding development in the U.S. were AMF Caterpillar Tractor Co., and Rockwell International. All three companies worked on friction welding machines in the early 1960s. Rockwell had several double-ended machines built for its own use to weld spindles to truck differential (banjo) housings, but they never sold any of these units to outside customers. Caterpillar made its first machine in the tool room to weld its own precombustion chambers for diesel engines. The first two machines actually sold were an AMF unit to weld steering worm shafts and a machine built by Caterpillar for turbochargers. Both companies used flywheels as a capacitor to store all or part of the energy for welding. Caterpillar called its system Inertia Friction Welding, while AMF called its system Flywheel Friction Welding.

In 1968, Caterpillar settled a patent dispute with AMF and became the sole owner of all AMF patents related to friction welding. AMF had sold about 50 machines at that time. The AMF machines were very well designed; fast, versatile with hybrid weld cycles which are only duplicated today using computers. In hindsight, Caterpillar should have continued to develop the AMF design, but it opted to discontinue this line and only develop its own version of stored energy welding machines.

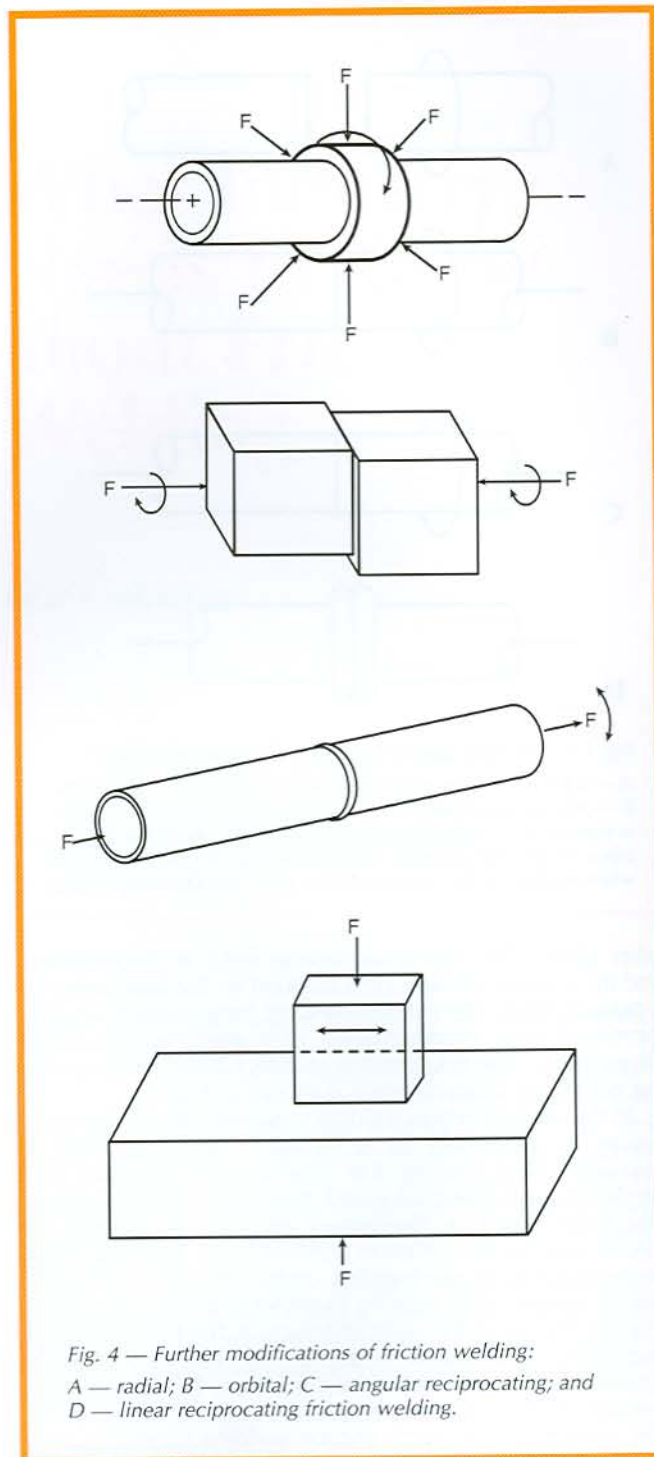


Fig. 4 — Further modifications of friction welding:
A — radial; B — orbital; C — angular reciprocating; and
D — linear reciprocating friction welding.

In 1975, Manufacturing Technology, Inc. purchased all rights and know-how from Caterpillar for the inertia welding process and the AMF process. In 1985, MTI added the Friction Welding know-how from the New Britain company.

How Much Does It Cost?

One of the handicaps of friction welding equipment is the price. A machine with 1-in. (25-mm) diameter capacity with manual loading and unloading will start at about \$200,000. The price will increase fast with options such as automation, flash removal, and computer monitoring. The buyer should not be surprised to pay 50% to 100% more for a fully "loaded" machine with automation.

I will take the risk of being criticized and make a graphic display of weld capacity of a basic tooled but manually loaded machine vs. price — Fig. 5.

Why Should You Use It?

Friction welding has numerous selling points. Here are a few of them:

- 1) Machine-controlled process; no human errors or judgments.
- 2) The machines use standard three-phase electricity at about 10-15 kW/inch² of welding capacity.

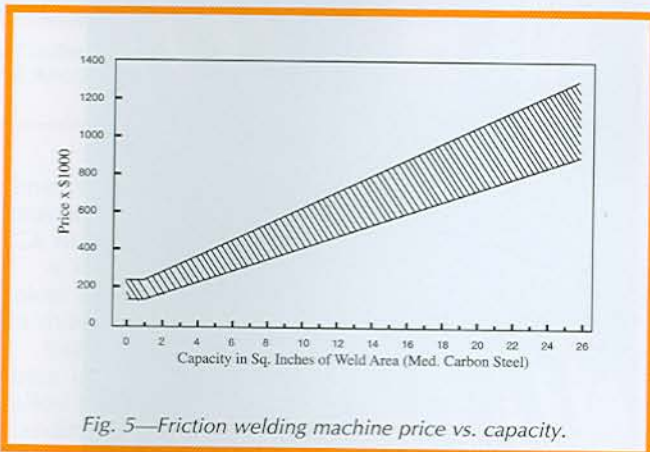


Fig. 5—Friction welding machine price vs. capacity.

- 3) The process is ecologically clean. There is no smoke, slag, or consumables such as flux, gas, or filler metal.
 - 4) Forged quality joints.
 - 5) 100% butt joint weld throughout its contact area.
 - 6) No solidification defects.
 - 7) No inclusion-type discontinuities (slag).
- Quench-hardenable materials may have to be stress-relieved or tempered to achieve full-strength welds.

What Materials Are Weldable?

As a rule of thumb, probably all metallic engineering materials which are forgeable can be welded by the friction process. Included in this category are automotive valve alloys, maraging steel, tool steel, alloy steels, and tantalum. In addition, many castings, powder metals, and metal matrix composites are weldable. Also, many dissimilar metal combinations such as copper-to-aluminum, titanium-to-copper, and nickel alloys to steel can be joined together by friction welding. Limited success has also been shown in the welding of some ceramics to aluminum as well as nodular or ductile iron to steel.

How about Various Part Geometries?

One part to be welded must have a nearly symmetrical shape (close to circular) around its axis of rotation. Hexagonal, square, octagonal, and elliptical shapes have

Table 1 — Fatigue Tests on Friction Welded Materials

Material	Type Test	Test Size	Heat Treatment	Hardness	% Unwelded Strength	Fatigue Strength
8630	Bending	0.438 in Dia.	Hardened after welding	Rc50	100%	± 108,000 psi at 2,000,000 cycle
8645	Torsion	2 in. Dia.	Hardened after welding	Rc48	93%	0-78,000-0 psi at 100,000 cycle
8620	Torsion	2 in. Dia.	Carburized & hardened after welding	Rc60	79%	0-57,000-0 psi at 100,000 cycle
1045	Torsion	2 in. Dia.	Hardened after welding	Rc54	97%	0-110,000-0 psi at 100,000 cycle
10B35	Torsion	2 in. Dia.	Hardened after welding	Rc50	100%	0-110,000-0 psi at 100,000 cycle
1141	Torsion	2 in. Dia.	Hardened after welding	Rc46	82%	0-69,000-0 psi at 100,000 cycle
1144	Torsion	2 in. Dia.	Annealed	Br 193	71%	0-35,000-0 psi at 100,000 cycle
1045	Tension	2 in. Dia.	Hardened after welding	Rc54	70%	± 44,000 psi at 200,000 cycle
10B35	Tension	2 in. Dia.	Hardened after welding	Rc52	73%	± 50,000 psi at 200,000 cycle

Source: *Automotive Industries* (September 15 1977)

Table 2 — Mechanical Test Results of Inertia Welded Parts

Material	SAE9310		SAE4340		SAE4340M		Nitalloy 135 modified		HP 9-4-30 IW and Stress Relief	
	Base Metal	Weld Zone	Base Metal	Weld Zone	Base Metal	Weld Zone	Base Metal	Weld Zone	Base Metal	Weld Zone
Yield strength (ksi)	113.950	114.050	188.950	199.000	201.500	203.450	145.650	142.950	209.000	212.000
		116.250		198.550		203.900		145.900	204.000	212.000
		117.600		189.200		203.500		146.800		215.000
Ultimate strength (ksi)	122.400	122.600	217.100	218.750	216.100	219.100	166.500	162.550	229.000	233.000
		124.600		215.700		220.600		166.000	229.000	233.000
		125.650		212.250		219.100		168.600		266.000
Elongation (%)	20.3	18.8	10.9	9.4	15.6	14.1	15.6	14.1	17	17.8
		18.8		9.4		14.1		14.1		15.0
		17.2		10.9		14.1		14.1		17.6

Source: *Machine Design* (December 16, 1990)

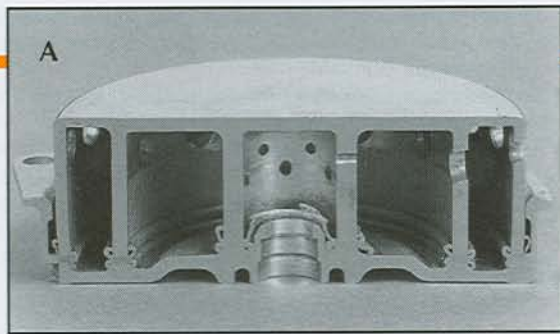


Fig. 6 — The types of parts produced by friction welding cover a wide range: A — airbag inflators; B — compressor rotors for aircraft engines; C — helicopter landing gear; D — power tool extensions.

been welded. Furthermore, one part should be of reasonable dimensions since it will be rotated in a lathe-type chuck. The second part to be joined can be of any shape or form as long as the weld contact area is a "butt" design.

Machines are available to spin from 1 mm (0.040 in.) diameter to 1 m (39 in.) with about the same length. As far as the maximum weld area is concerned, machines are available to weld from 1 to 161,000 mm² (250 in²) based on medium carbon steel.

How Strong Are These Welds?

Most metals can be welded and postheat-treated to 100% base metal strength. However, based on some literature research, the following information may be useful. Table 1 shows the results of fatigue tests on friction welded alloys, while Table 2 displays the mechanical test results of inertia welded parts.

All welds should go through a thorough development and be tested for the purpose intended. (This is a waiver for all product liability lawyers.)

What is the biggest danger to the quality of the weld? The answer to this question is the base metal itself. This answer may seem odd, but it is true. Free machining constituents such as sulfur and lead weaken the weld since they orient

themselves in the weld zone. The same is true with other base metal discontinuities, such as stringers, laps, voids, slag, and inclusions. The friction weld cannot "repair" damaged base metal nor will it be stronger than the transverse properties of the welded metal.

Where the Process Is Used

At present, the most active market for friction welding is in the automotive industry. Among the more widely welded components in automotive are turbochargers, airbag inflators (Fig. 6A), drive shafts, exhaust valves, hydraulic jacks, and rear axles.

The largest friction welding machine in the world is in operation at the GE Aircraft Engines' facility in Wilmington, N.C. — Fig. 7-A Model 800 inertia friction welding machine. This 2000-ton machine features 600 hp (total) and it operates hydraulically. Obviously, this machine has been designed around aircraft engine alloys and applications. However, if someone wanted to weld steel with this type and size of machine, it would be possible to weld about 230 in.² in tubular configurations. This could be done in a weld cycle of less than eight minutes. If this same machine had been built as a direct-drive friction machine, we would have needed a minimum of 4000 hp drive. To the best of my

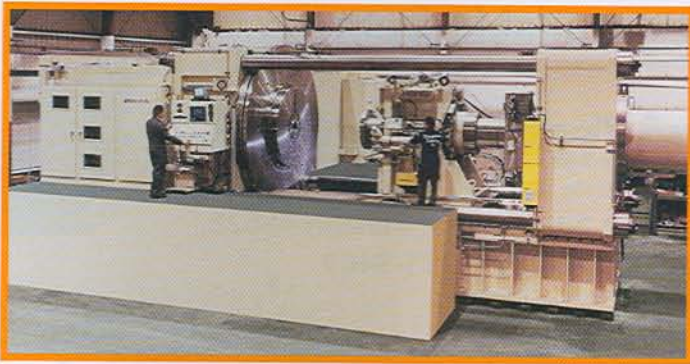


Fig. 7—The largest friction welding machine in the world is in operation at GE Aircraft Engines. It is an inertia friction type.



Fig. 8—A modern direct-drive friction welding machine, complete with computer controls, DC drive, and flash removal.

knowledge, the largest direct-drive friction welding machine ever made is a 300-ton unit. Thus, the machine at GE Aircraft Engines is larger by a factor of eight.

A modern direct-drive friction welding machine, complete with computer controls, DC drive, and flash removal is shown in Fig. 8.

Examples of familiar parts friction welded in other industries include a compressor rotor made of a nickel-based alloy for a four-stage aircraft engine (Fig. 6B); a helicopter landing gear (Fig. 6C) consisting of AISI 4340 steel tubing welded to a 4340 forging; power tool extensions (Fig. 6D) wherein mild steel tubes are welded to alloy steel ends. In the sports world, some golfers are putting with clubs where the shafts are friction welded to the putters.

What Standards and Specifications Are Available?

Presently, the only specification in the U.S. is the Mil-Std-1252 specification. In addition, there are British and German Standards. The German standard is DVS 2909, while the one from England is BS 6223. The AWS C6 Committee on Friction Welding is about ready to release a U.S. standard. We hope that the military will adopt the same specification. Most larger corporations have their own specifications for friction welding.

Where Can You Read More about Friction Welding?

Recommended further reading includes:

- 1) *Recommended Practices for Friction Welding*, ANSI/AWS C6.1-89. This volume can be purchased from AWS.
- 2) Chapter 28 of the *AWS Welding Handbook*, Eighth Edition, Volume 2, is devoted to friction welding.
- 3) *Source Book on Innovative Welding Processes*, Ohio, 1981.

There have been volumes of research papers written over the years which are available in most libraries. Look for key words such as: Friction welding, direct-drive friction welding, flywheel friction welding, friction forging, inertia friction welding, solid-state bonding, and spin welding.

Who Makes the Equipment?

There are two domestic manufacturers, two English manufacturers, one German manufacturer, and three Japanese manufacturers of friction welding equipment. The U.S. manufacturers are Advance Technology, Troy, Mich., and

Manufacturing Technology of South Bend, Indiana. An overseas manufacturer with sales and service in the United States is Thompson Welding Systems (KUKA) of Sterling Heights, Michigan. Other manufacturers of friction welding equipment include three companies: Nitto Seiki, Toho, and Toyoda, from Japan, Black Friction Welding from England, and KUKA in Germany.

In addition, there are a number of manufacturers in Korea, England, China, Russia, and India which produce for their home markets only or specialize in a single machine model for a specific purpose.

Sources Capable of Performing Development Work

All manufacturers of equipment will consult on and develop friction welded joints and have R & D machines, as well as job shops, available. An independent source in this regard is Edison Welding Institute, Columbus, Ohio.

Should you want to develop prototypes or short test lots, expect to pay for those services. The R & D machines, specific tooling for your parts, and a metallurgist are not free. Prices will range from \$500 minimum for simple small parts to thousands of dollars for larger (aircraft type) part development.

The friction welding industry is also well represented by a number of job shops in the U.S. and Canada. Here is a list of some of those shops:

ARD, Cambridge, Ontario, Canada; American Friction Welding, Brookfield, Wisconsin; Chicago Turnright, Chicago, Illinois; Interface Welding, Carson, California; Novatech, Dallas, Texas; Special Welding Services, Saginaw, Michigan; Spinweld, Milwaukee, Wisconsin; and TCR Corp., Minneapolis, Minnesota. Manufacturing Technology also operates a job shop in South Bend, Indiana.

Summary

Friction Welding is a reliable, repeatable, solid-state process which has been used for many years. It is ecologically clean with a minimum of weld-caused discontinuities when compared to other welding processes.

The main purpose of this article has been to answer the many questions asked of me over the past 20 years about friction welding. ♦

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FRICION WELDERS

Manufacturing Technology, Inc. has been a leading manufacturer of Inertia Friction and Direct Drive Friction welders since 1976. Advantages of MTI's welding process include:

- Available machines can weld components from .040 in. (1mm) to 225in² (145,160mm²).
- Machines are versatile enough to join a range of part shapes materials and weld sizes.
- Dissimilar metals can often easily be joined, such as aluminum to steel.
- Powder metal parts can be welded together, or welded to forgings, castings, or wrought material.
- Equipment easily automated for high production rates.
- Process parameters are easily monitored; data can be stored for critical applications.
- No weld spatter and few sparks produced.
- No consumables required - no flux, fillers, or shielding gases.
- No objectionable smoke, fumes, or gases generated which need to be exhausted.

FRICION WELDING JOB SHOP

Manufacturing Technology, Inc. maintains an in-house friction welding job shop, providing Research & Development and production welding services for customers. Capabilities include:

- Material size may range from .250 in. diameter to 6 in. diameter solid, or 43 in² tubular steel.
- Machines available for production runs, ranging from 6-ton to 450-ton weld force.
- Production run quantities may be large or small, depending upon your requirements.
- Pre- and Post-weld processing is available.
- Weld development feasibility studies completed by experienced professionals.
- Metallurgical evaluation - Metallurgist on staff to evaluate weld quality.
- Design capability for both tooling and parts by experienced Design Engineering Department.
- Computer storage of parameter data is available for critical applications.

DESIGN SERVICE

Adams Engineering, a division of **Manufacturing Technology, Inc.**, has been providing design services for over 40 years. We specialize in tool, die, jig, fixture, gage, special machine and product design. General drafting services are also available.

- Capabilities to handle any job - no job too large or too small.
- Competitive rates (design/drafting rates available upon request).
- Work details remain confidential.
- Timely deliveries - Computer Aided Design department runs 24 hours/day.
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