MACHINE DESIGN

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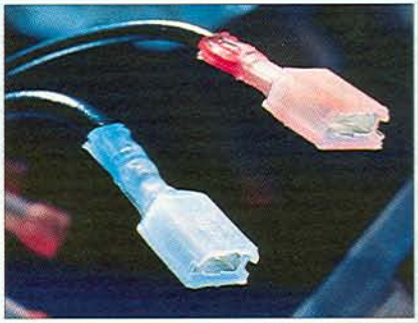

Quick Disconnects

LIGHTWEIGHT, FIGHTS GREAT

Building strong bonds with INERTIA WELDING

Inertia welding joins dissimilar metals without reducing their strength.

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Inertia welding offers an alternative to machining from solid bar stock, forging, or casting to produce near-net-shape parts. The process eliminates costly machining operations and extra material, and reduces set-up and operator time. Results include reduced cost, the possibility of reduced inventories, and substantial improvements in quality.

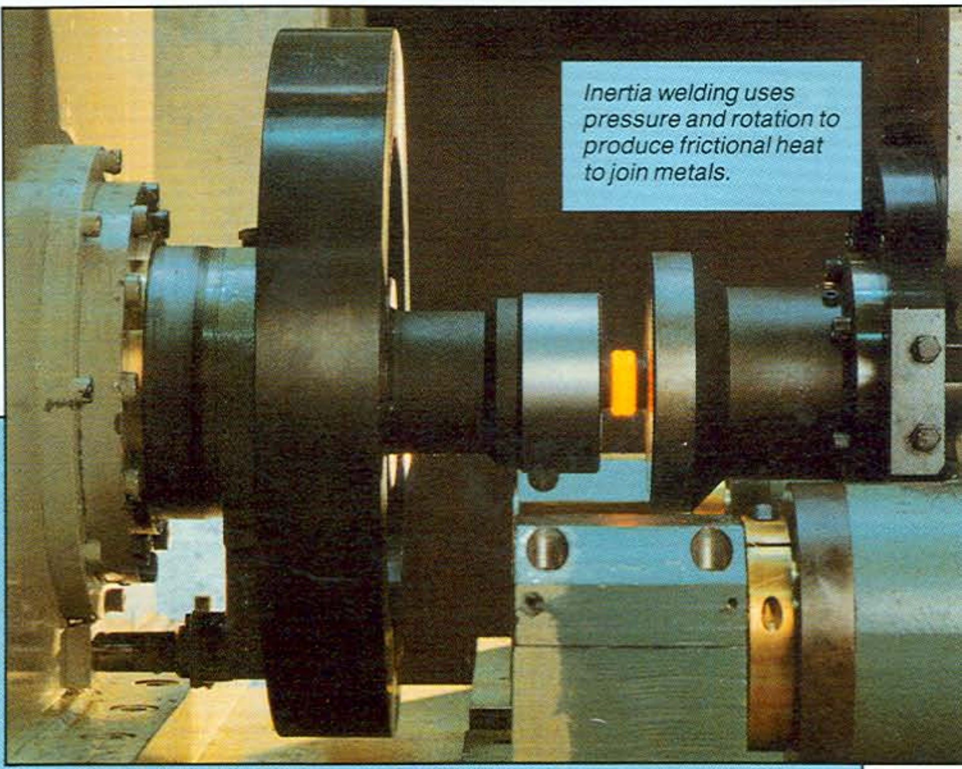
Inertia welding is used in the aerospace, automotive, and nuclear industries for components such as gears, drive shafts, turbine wheels, and valves. Parts for cryogenic applications, such as pumps for liquid gas, may also be inertia welded.

Inertia welding is a solid-state joining process that forges together metals, whether or not they have similar compositions. For example, the process can join ferrous and nonferrous metal components.

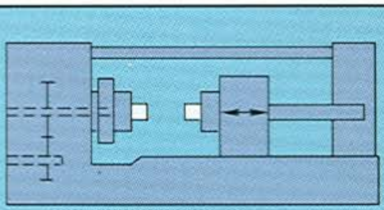
Unlike conventional welding processes, welds are made without melting either of the two base metals. Instead, the metals are forged together using extremely high pressure and rotational forces. Surface speed of the components to be joined varies between 750 and 3,000 surface feet per minute (sfm). Because the weld takes place so quickly and the joining temperature is relatively low, the heat-affected zone is controlled closely.

Joining steels

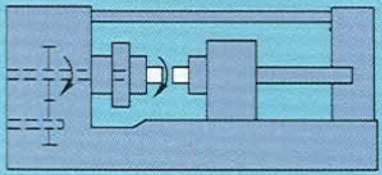
Two experiments were designed to show the suitability of inertia welding in different situations. The first experiment was to establish expected mechanical properties for



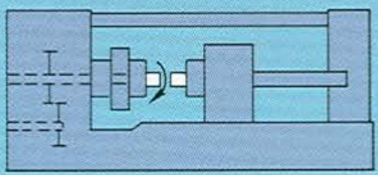
Inertia welding uses pressure and rotation to produce frictional heat to join metals.



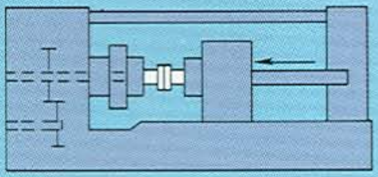
To be inertia welded, the workpieces are first mounted in the machine. At least one of them must be axially symmetric, because it will be rotated.



The drive is engaged and the piece is run up to weld speed.



Then the drive is disconnected, and inertia keeps the piece rotating.



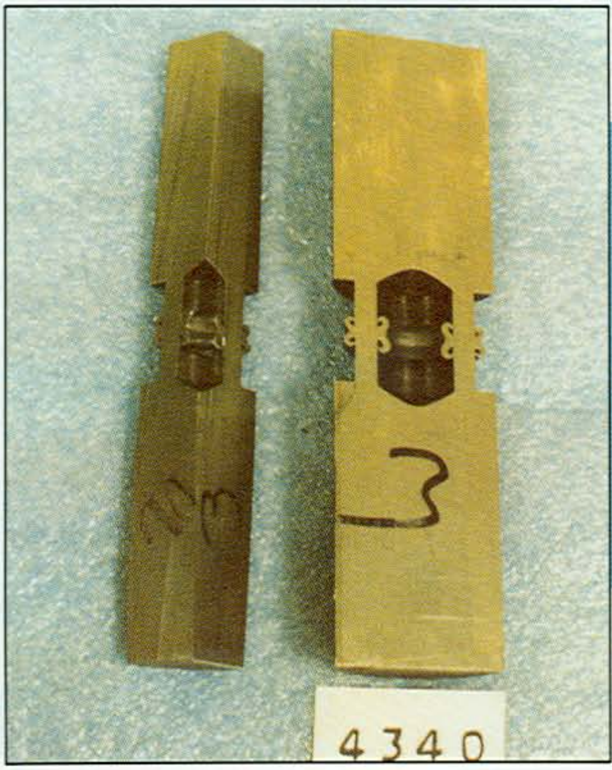
The pieces are brought into contact, and the weld is formed.

various steels after welding. The second experiment showed results of postwelding treatments for one particular material.

Steels used in the first experiment were SAE 9310, SAE 4340, SAE 4340M (300M), Nitralloy 135 modified, and combinations of these materials. The candidates were selected from the structural-steel family, most commonly used in the aerospace, automotive, and nuclear industries. Inertia welding is also applicable to core-hardened steels, carburized or nitrided components. However, a certain amount of stock must be left untreated to ensure a reliable joint.

The tests were limited to structural steels used for their through-hardening or surface-hardening characteristics, such as carburizing or nitriding. Only in these applications does the user need to verify that mechanical properties are maintained. With other materials, inertia welding is more often used for other advantageous engineering properties, such as corrosion resistance, weight savings, or reducing the amount of extra work needed to produce the end component.

Test samples for all materials were machined from 2-in. bar stock and heat treated before the test. The detailed treatment consisted of normalizing, hardening, and tempering to the hardness ranges



Longitudinal sections show the inertia weld before machining. These test sections were then ground to ensure that the weld joint was in the center of the section. Crushform grinding was used to avoid work hardening that could have affected test results.

Mechanical properties of HP 9-4-30 after various thermal processes.

Material condition	Yield (ksi)	Ultimate (ksi)	Elongation (%)	Reduction of area (%)
Base line heat treated per AMS 2759/2	209.000	229.000	17.0	62.1
	204.000	229.000	17.0	60.9
Inertia welded and stress relieved only	212.000	233.000	17.8	62.8
	212.000	233.000	15.0	58.5
	215.000	236.000	17.6	58.6
Inertia welded and re-heat treated per AMS 2759/2	219.000	240.000	16.0	61.0
	222.000	242.000	15.7	61.1
	217.000	240.000	16.0	61.5
Inertia welded, re-normalized, and heat treated per AMS 2759/2	216.000	235.000	15.0	54.3
	218.000	237.000	16.5	62.4
	216.000	236.000	12.0	44.3

Different heat treatments are standard for various materials to develop similar properties. Specifications are available for the treatment of each of these materials.

Test results show that yield and ultimate strengths in the weld zone are comparable to, and sometimes greater than, those of the base metal. However, welds between dissimilar metals have strengths closer to the weaker metal.

Mechanical test results of inertia welded parts

	SAE 9310		SAE 4340		SAE 4340M		Nitralloy 135 modified	
Material	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
		116.250		198.550		203.900		145.900
		117.600		189.200		203.500		146.800
Ultimate strength (ksi)	122.400	122.600	217.100	218.750	216.100	219.100	166.500	162.550
		124.600		215.700		220.600		166.000
		125.650		212.250		219.100		168.600
Elongation (%)	20.3	18.8	10.9	9.4	15.6	14.1	15.6	14.1
		18.8		9.4		14.1		14.1
		17.2		10.9		14.1		14.1

indicated in the preheat treatment table.

Tensile bars were also processed at this point. These nonwelded bars of metal functioned as controls in the experiments, also serving baseline reference in the results.

Each type of structural steel has its own prescribed process cycle. Whether or not the bars are inertia welded, they must receive this heat treatment to develop the necessary core properties. To obtain valid information on the effect of inertia welding, all test coupons were processed as prescribed.

The inertia-welding parameters for all steels in the tests were identical, with weld speed at 2,100 rpm, and weld pressure at 27,500 lb thrust load. Varying the weld speed and pressure affects the strength of the weld and the size of the heat-affected zone.

Test results showed that upset ratios, or loss of length, differed for the various steels. SAE 9310 lost 0.389 in.; SAE 4340, 0.270 in.; SAE 4340M, 0.275 in.; and Nitralloy 135 modified lost 0.307 in. Upset ratios will vary with alloy composition and core strength of the component to be processed. However, these factors can be readily established during preproduction tests and are repeatable to within 0.005 in.

After joining the two test sections, all samples were stress relieved at 300°F for 3 h within 30 min of welding to prevent stress cracking. Then all parts were retempered at 1,000°F for 2 h.

All inertia-welded test samples were sectioned longitudinally by abrasive cutting. Tensile bars were crushform ground from these sections to ensure that the weld joint was positioned exactly in the center of the gage length. These precautions were taken to ensure that neither abrasive cutting nor the preparation of the tensile bars could adversely affect the mechanical properties. Crushform grinding, a precision grinding process, provided the configurations needed for the tests without altering the potential test data. Normal machining could have work hardened the welded samples, affecting the test data.

SAE 9310 to SAE 4340 Weld zone	SAE to 4340 SAE 4340M Weld zone
115.600	183.500
115.450	191.400
111.700	201.000
123.850	218.850
128.200	208.400
128.200	218.600
15.6	9.4
18.8	8.9
18.8	9.4

After welding, the samples were examined for metallurgical properties. To determine the effectiveness and integrity of the metal joint in the interface region, the weld zone was examined for inclusions, grain size and structure, degree of grain refinement, and heat-affected zone. No detrimental conditions were observed in any of the test sections.

Analyzing material treatments for HP 9-4-30 shows that simply relieving the stress in the workpiece produces properties very close to those of the base metal. Heat treatment and renormalization increase strength, but not enough to justify their extra cost.

Pre-heat treatment of the various engineering materials

Alloy	Treatment
SAE 9310 (AMS 6265)	Normalize at 1,725°F, austenitize at 1,500°F and oil quench, then temper at 1,000°F to R_c 23 to 27.
SAE 4340 (AMS 6414)	Normalize at 1,650°F, austenitize at 1,500°F and oil quench, then temper at 1,000°F to R_c 40 to 43.
SAE 4340M (AMS 6417)	Normalize at 1,700°F, austenitize at 1,600°F and oil quench, then temper at 1,050°F to R_c 43 to 46.
Nitralloy 135 modified (AMS 6471)	Austenitize at 1,725°F and oil quench, then temper at 1,100°F to R_c 34 to 38.
HP 9-4-30	Normalize at 1,700°F and subcritical anneal at 1,250°F-4 h. and 1,150°F-4 h. Austenitize at 1,550°F and vacuum gas quench, subzero treat at −100°F, then double temper at 1,000°F for 4 h. to R_c 46 to 50.

MIL-STD-1252, which covers inertia welding, requires etching the part to examine the heat-affected zone. This shows how far the zone extends, as well as giving an indication as to how different it is from the base metal. When inertia-welded samples were etched, the weld zone was barely distinguishable from the base metal.

The mechanical test results for all samples confirmed that no loss of strength occurred in any of the structural steel sections due to inertia welding. The weld joint is cleaner than the base material, more homogeneous and fine-grained. This indicates better metallurgical properties in the welded zone. The inertia welding process produces a forge effect on the grain structure, making it finer, which in turn improves the toughness and ductility of the steels processed.

Heat treatment

In the second experiment, design engineers wanted to learn to what extent HP 9-4-30 properties would change as a result of different thermal treatments after inertia welding. There were three variables: retemper only, reharden and retemper, and applying the total cycle, from normalizing, hardening and tempering.

Specification AMS 2759/2 allows three routes after welding a previously heat-treated component. The part can simply be retempered at 1,000°F for 4 h. It can be rehardened and retempered. This involves austenitizing the part at 1,550°F in vacuum for 1 h, quenching it to ambient temperature, then double tempering it at 1,000°F for 4 h. The third choice is to normalize, reharden, and retemper the part. This is done by heating it to

Inertia welding is often used to join two different metals. Here, copper and stainless steel are welded to aluminum. Preliminary results of recent tests indicate that such welds, like those between steels, can be made with little or no loss of strength.

1,700°F and cooling to ambient temperature, subcritical annealing at 1,250°F for 4 h, then at 1,150° for 4 h, then following the reharden and retemper instructions.

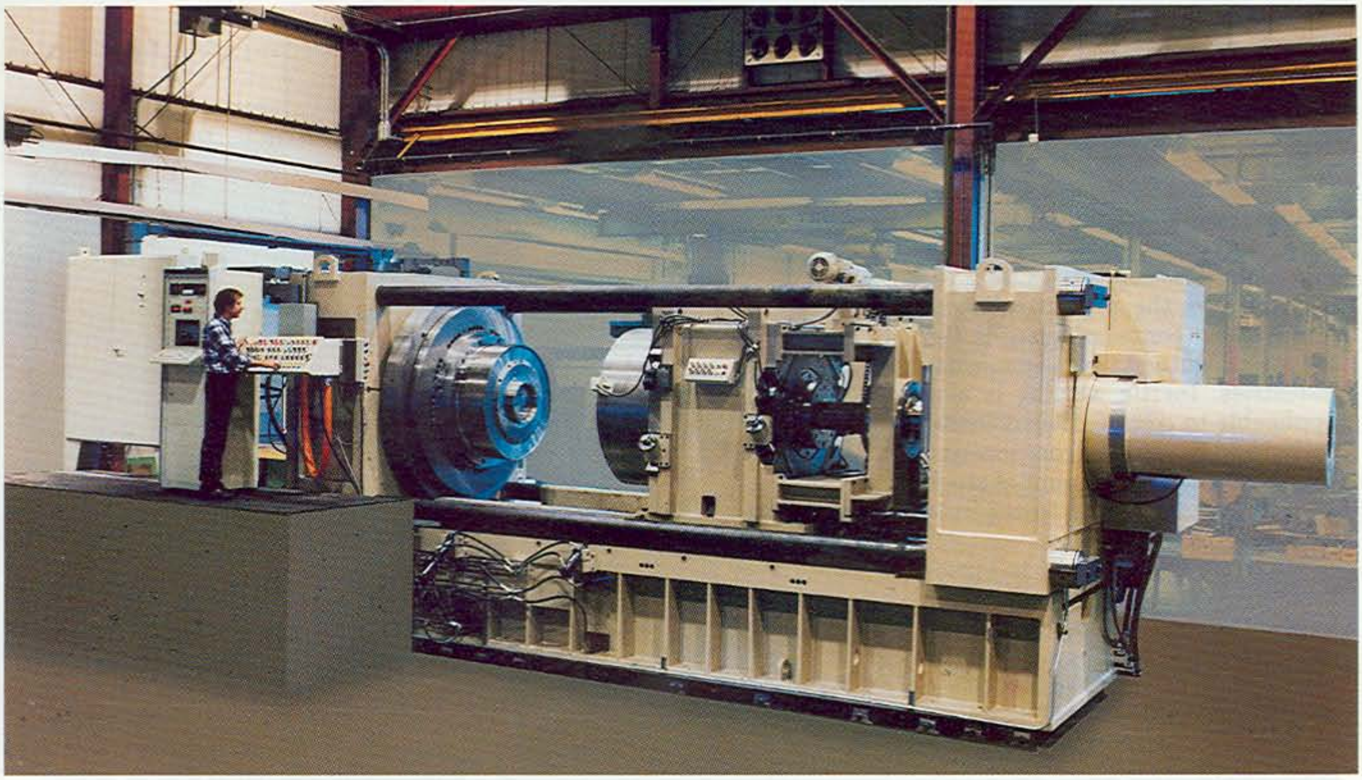
Rehardening and retempering costs about four times as much as simply retempering. Normalizing, rehardening, and retempering costs about three times as much as just rehardening and retempering. Nonwelded samples were processed in the three manners to generate baseline data.

The HP 9-4-30 test parts — were treated as follows after welding: Sample 1 was only retempered. Sample 2 was subcritical annealed then rehardened per AMS 2759/2. Sample 3 was normalized and rehardened per AMS 2759/2.

The experiment with HP 9-4-30 parts demonstrates that simply stress relieving the part after inertia welding gives properties comparable to those of the test section, which was heat treated before inertia welding. Re-heat treatment slightly improved the mechanical properties of the treated sections, but not enough to make it worth the additional processing cost. A complete re-heat treatment, including normalizing, actually showed a slightly lower strength level and cannot be justified.

For all the engineering alloys in the test group, tests confirm that inertia welding offers cost savings and quality improvement without sacrificing any of the mechanical strength properties. More recently, tests performed on welds of aluminum and titanium to stainless steel show favorable preliminary results.

All inertia-weld testing was performed at Interface Welding, Carson, CA, with the assistance and support of Mr. A. Wadleigh, president of the company.



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