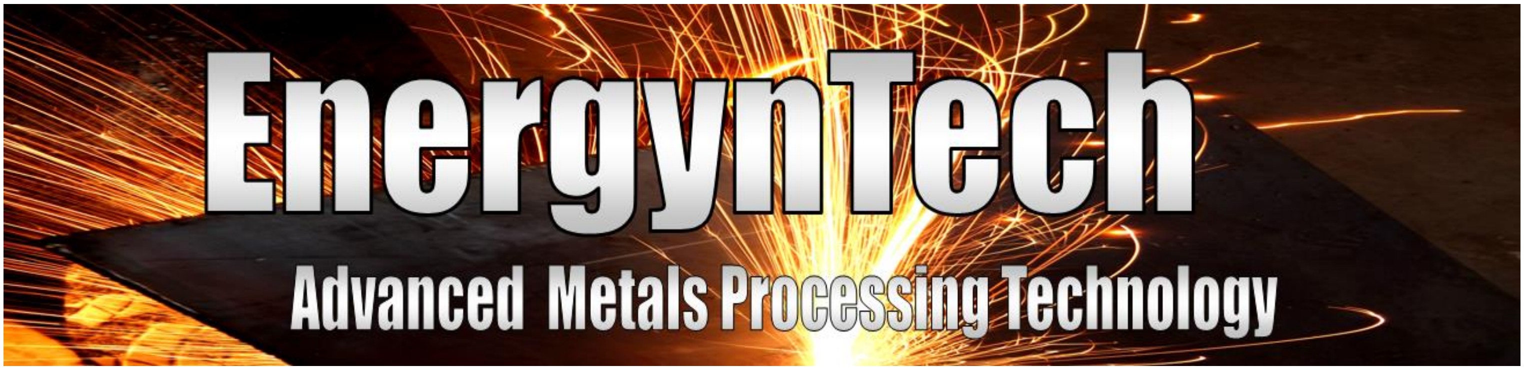
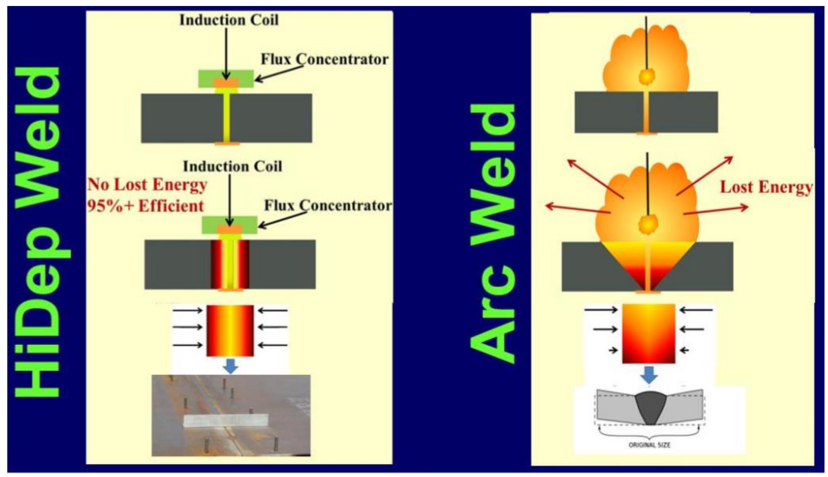


HiDep™ (Hybrid Induction Arc Welding): High deposition rate welding is a completely new process. It is an arc welding process, but what makes it new is an induction heating coil which runs ahead of the arc welding torch. The induction heating raises the surfaces of the weld joint up to the melting point. The arc welding equipment is similar to traditional arc welding, but the addition of the induction heating gives the process several advantages, including: faster welding, simpler and lower cost weld preparation, and balanced heating to minimize or eliminate weld distortion.

THE HiDep PROCESS



The arc plasma is a heat radiator. Heat radiates from the arc plasma and heats objects which are closest to the radiating heat. So the side of the weld exposed to the arc is heated more. Upon cooling, the hotter material shrinks more than the material further from the arc, causing the plates to distort.

With induction, the heat is generated by electrical resistance to eddy currents in the interior of the part. The eddy current is induced by an AC electromagnetic field from the induction coil. This electromagnetic field is directed precisely with the flux concentrator, so only the areas to be heated become hot. The highly concentrated heat source can heat even thick steel parts up to near melting in 1 or 2 seconds. Heating this fast can provide the necessary heat to weld at 5 to 8 feet per minute – more than double the speed of arc welding, and more than double the productivity of arc welding.

THE COST OF WELD DISTORTION

The straightening of decks, bulkheads, and hulls due to weld distortion costs approximately $30,000,000 annually. When coupled with other costs, such as fit-up, added welding, re-work, scheduling delays, and other production problems, that cost escalates. Since much of the remedial work, and other costs are generally indirect costs, the total burden of weld distortion cannot be determined with certainty. It is several times that of the straightening costs.

HIGHER WELDING SPEED

As welding speed increases productivity increases. The addition of induction heating results in a 1.5 to 3+ times increase in welding speed. In addition, the induction heating facilitates the use of a square weld preparation. This eliminates bevel cutting which cuts the cost of cutting plate by 66% in preparation for welding. With the edges of the weld already at the melting point the arc melts into the plate all the way to the bottom of the joint easily, so a very narrow gap (e.g., 1/16”) can be welded. The result is a reduction in welding wire use by as much as 75% (when compared to submerged arc welding).

HiDep weld joining two 8 foot X 20 foot plates of 3/8” thick EH-36 Marine Steel. The weld was demonstrated for the HiDep Project Team, NSRP representative, NAVSEA representative, and the NSRP PTR. Completed outdoors in a shipyard like production environment. The weld exhibits virtually zero weld distortion.

HiDep weld joining two 8 foot X 20 foot plates of 3/8” thick EH-36 Marine Steel.

PROCESS IMPROVEMENTS OVER ARC BUTT WELDING

Significant process improvements:
Angular distortion reduced by 88%
Welding Speed increased by 2X up to 4X
Welding costs decreased by 50% - 75%

Metric	"as is" Baseline	Project Goal	Phase I Results	Phase I Improvement	Success
Distortion Angle	> Fails Navy Rqmt. 35% of the time	50% improvement	100% All test welds meet Navy Requirements	88% reduction of distortion angle	✓
Production Speed	20 in./min.	50% improvement	30 in./min.	50% improvement	✓
Welding Cost	> $37 / 40 ft. weld 0.625 inch thick steel	50% improvement	Weld Speed ↑ 50% Wire Use ↓ 75% No Bevel cut Cost ↓: $15 per 40' weld	50%+ improvement	✓

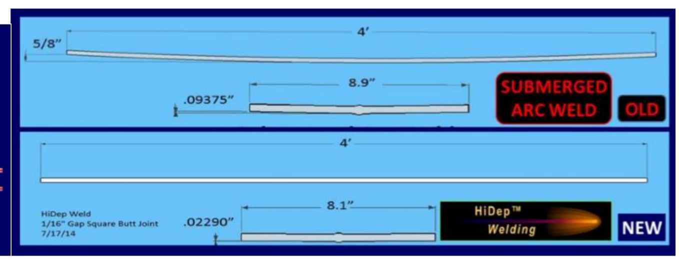
THE BUTT WELD TESTING RESULTS

Weld Testing showed that the process is widely applicable:

- Tensile Strength: Yield Minimum Required: 51 ksi
  Yield Strength Actual: 67.4 ksi
  Tensile Range: 70 – 90 ksi
  Tensile Strength Actual: 88.8 ksi
- Bend Test Results: Front Side – Accept
  Back Side – Accept
- Charpy Fracture Toughness Weld Metal (EH-36):
  Weld Required: 20 ft-lb @ -40° F
  Weld Results: 58 ft-lb @ -40° F
- Charpy Fracture Toughness Heat-Affected-Zone (EH-36):
  Weld Required: 20 ft-lb @ -40° F
  Weld Results: 43 ft-lb @ -40° F

Metric	Requirement	Results	NAVSEA	A.B.S.	Success
Strength	Yield: 51 ksi Tensile: 70-90	67.4 ksi 88.8 ksi	Passed Passed	Passed Passed	✓
Bend Test	50X Examination	No Defects	Accept	Accept	✓
Fracture Toughness Weld	25 ftlb @ -20° C 20 ftlb @ -40° C	69 ftlb @ -20° C 58 ftlb @ -40° C	Passed	Passed	✓
Fracture Toughness HAZ	25 ftlb @ -20° C 20 ftlb @ -40° C	75 ftlb @ -20° C 43 ftlb @ -40° C	Passed	Passed	✓
Weld Cross-Section	Shape and Size	Meets all Requirements	Passed	Passed	✓

THE HiDep BUTT WELD DISTORTION REDUCTION

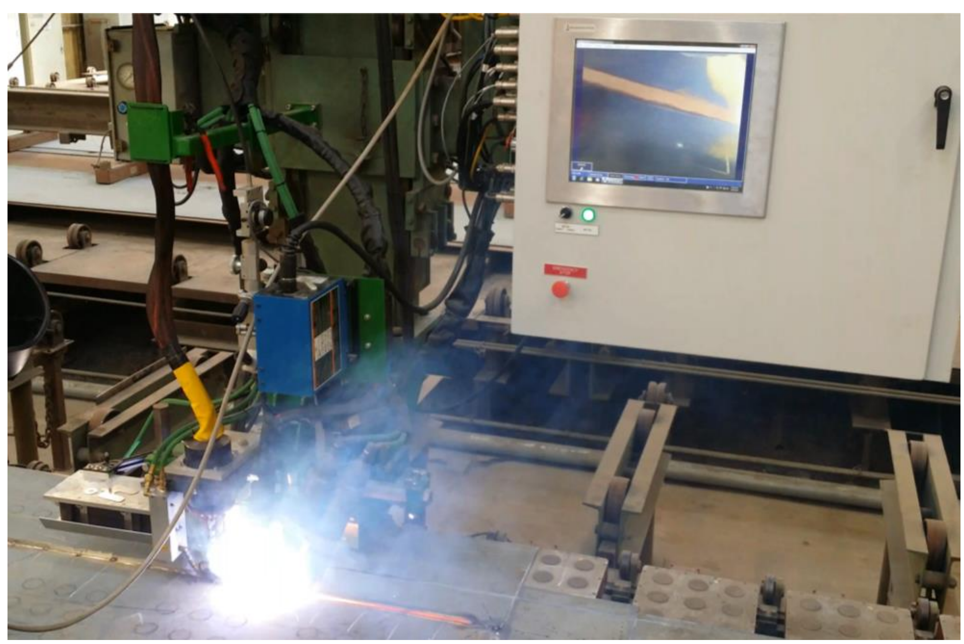


The baseline for much heavy fabrication butt joint welding is submerged arc. In comparison to submerged arc welding, the HiDep welding process eliminates over 88% of the angular distortion, and more than 70% reduction of longitudinal distortion. The 20 foot long weld (two 20'X8' EH-36 Steel Plates, shown on page 1) had no measurable longitudinal distortion. The HiDep welding process is applicable to most heavy fabrication Butt Joint welding.

THE HiDep BUTT WELD PROCESS APPLICATION

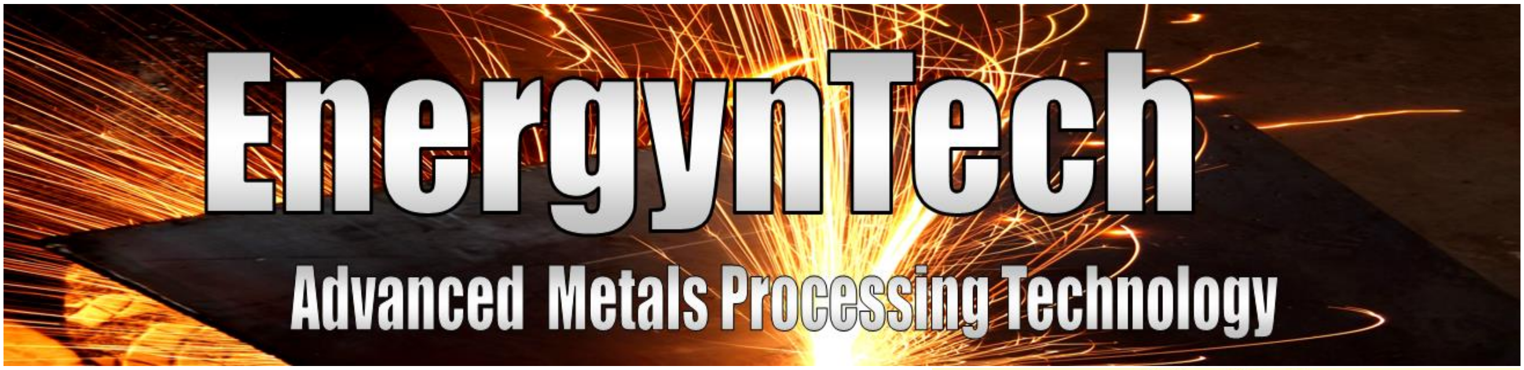
The shipbuilding industry has many areas where weld distortion creates problems and generates significant costs. Butt joint welds in panel lines exhibit both angular distortion as well as significant longitudinal distortion. T-Fillet welds distort deck, bulkhead, and shell plate panels.

The HiDep Butt Weld process is equally applicable to all types of heavy fabrication welding, including towers, tanks, pipelines, building structures, bridges, etc. The process can be automated in factories using conventional Gantry Welding Systems. In addition, portable and mobile robots can be used to produce field welds.



HiDep™ welding system joining 4.5mm EH-36 Marine Steel (Equivalent to ASTM A709 Grade 50). System is installed at Bollinger Shipyards, LLC, which produces the U.S. Coast Guard Fast Response Cutter ship.

Information:
EnergynTech, Inc.
11354 W. 13th Ave. Lakewood, CO 80215
Contact:
Jerry E. Jones: 720-232-3490
Jonesje1@aol.com



iCut™ (Hybrid Induction Plasma Cutting): High speed cutting by utilizing an induction coil ahead of the weld maintaining a minimum of 1600° F. Cutting of steel is assisted by oxygen. The oxidation of iron, once it is up to the "Autoignition" temperature of 1600° F, is a highly exothermic reaction which produces significant amounts of heat. The key to the process is to maintain the of 1600° F temperature on the top surface of the steel. Induction can maintain that temperature at a speed of 72 – 100 inches/minute.

COMPARISON OF iCUT PROCESS FOR CUTTING

The iCut process is similar to oxyfuel cutting or plasma cutting where a stream of oxygen is used to oxidize the iron in the metal which is a highly exothermic reaction. The oxidization of the iron is the primary source of heat for cutting. The induction coil can maintain the autoignition temperature on the metal surface at speeds up to 100 in./min. The coil used for iCut heats the surface with 1.4 billion watts per square meter, while the heat from a flame in oxyfuel welding only has about 48 million watts per square meter of available heat.

Comparison to Oxy-Fuel Cutting

$q'' =$ **Heat flux (W/m²)** **(assume 25 mm²)**
$= 48{,}880{,}000$ **(acetylene)**
$= 46{,}971{,}000$ **(propane)**
$= 1{,}400{,}000{,}000$ **(35 kW induction)**

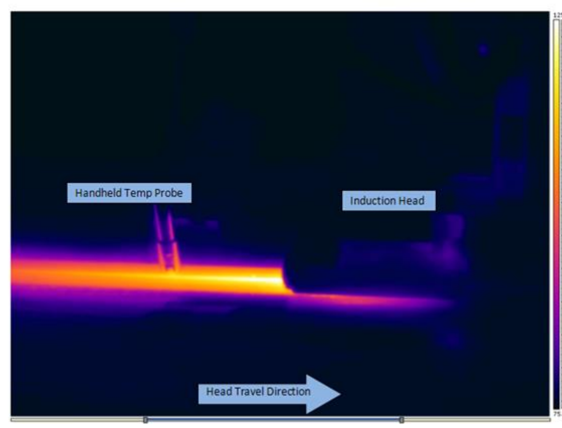
Scientific Concept

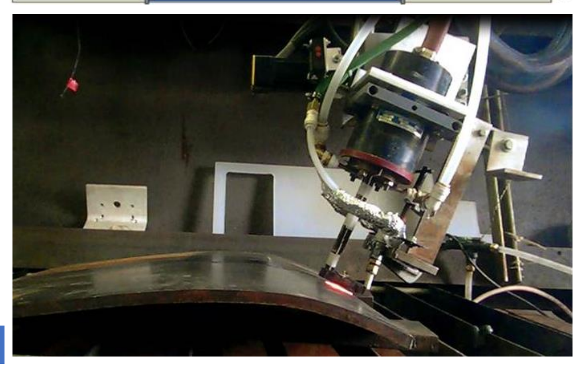
Thermal Comparison to Oxy-Fuel Cutting

$$t_{ig} = \left(\frac{\pi}{4}\right)(k\rho c)\left[\frac{T_{ig} - T_o}{q''}\right]^2$$

t_{ig} = **Time to reach autoignition temperature,**
κ = **Thermal conductivity (W/(m-°K)),**
ρ = **Density (kg/m³),**
c = **Specific heat capacity ((J/(kg-°K)),**
T_{ig} = **Autoignition Temperature (°K),**
T_0 = **Ambient Temperature (°K),**
q'' = **Heat flux (W/m²)**

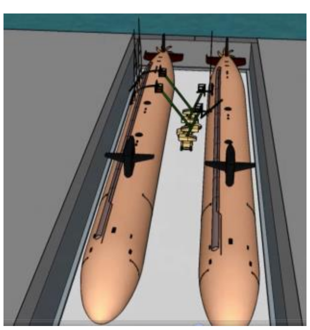
Infrared Camera test with Induction Only (No welding) - ½" plate, 1/8" gap Travel speed: 37 IPM (Min Temp 75F, Max Te

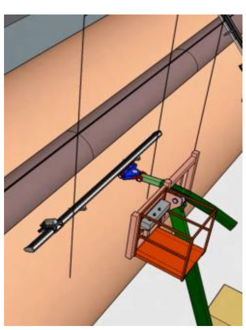




AUTOMATED CUTTING OF CURVED SUBMARINE HULL

The iCut process robotic system can follow an unknown surface at speeds of up to 100 in./min. The portable cutting gantry can be mounted on to a heavy carry capacity man-lift for field cutting of steel thicknesses 0.125" to 6" at speeds of 70 – 100 in./min. – see below.



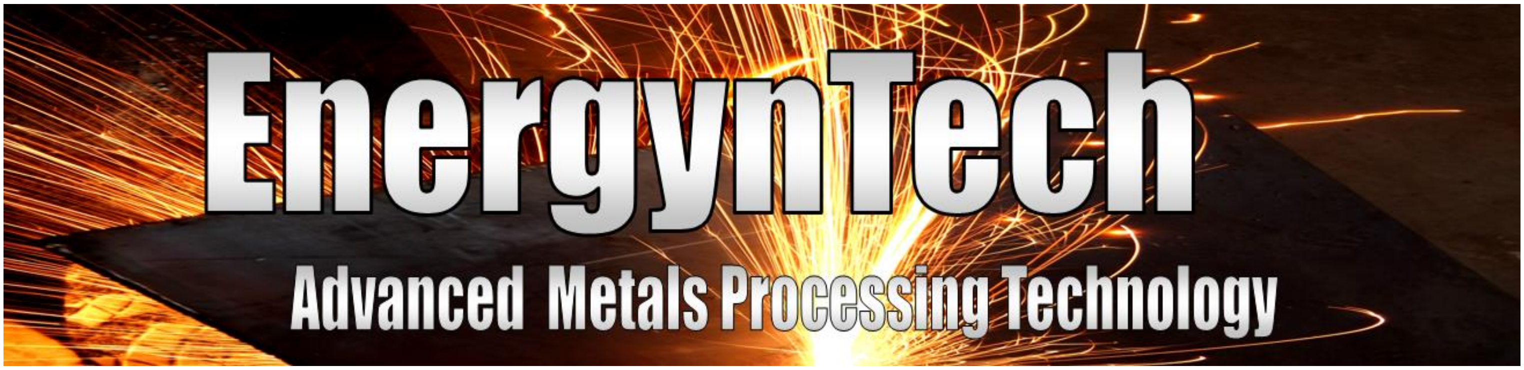


CUT QUALITY

Shipbreaking is used for demolition of decommissioned ships as well as to provide access to change or maintain large equipment. Oxyfuel cutting produces a rough cut surface (right). The iCut process produces a relatively smooth surface if the section of hull is to be replaced and welded into place (left).

Information:

EnergynTech, Inc., 11354 W. 13th Ave., Lakewood, CO 80215
Jerry E. Jones: 720-232-3490, jonesje1@aol.com

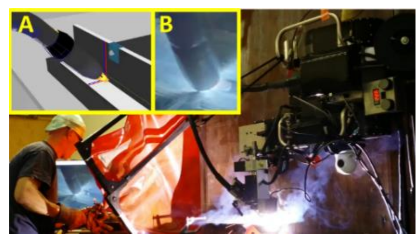


Based on data from the automobile industry, robots can reduce the cost of manufacturing by 2X and improve the quality 3X. But, for heavy fabrication in the field, the conventional robotics technology is difficult to use. Two primary differences between the automobile industry and, for example, the shipbuilding industry. To automated heavy field fabrication requires new and specialized robots that utilize Virtual Reality (VR) and Augmented Reality (AR)

VIRTUAL REALITY CONTROLLED MOBILE WELDING ROBOT SYSTEM

The mobile robot consists of a crawler with treads (like a miniature bulldozer) which are magnetic, so the system can work on vertical walls or even hang upside down. The crawler robot has a six-axis robotic arm, which has a heavy duty welding torch (bottom left of the picture).

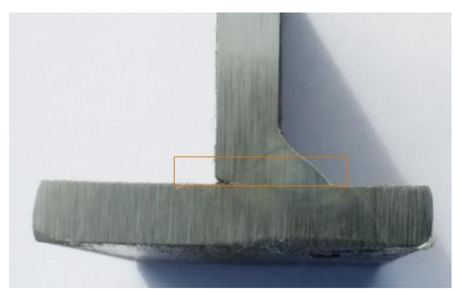
The Virtual Reality Cell (VR Cell) consists of a "suitcase" welder for adjusting the voltage and wire feed speed – typical of a field fabrication operation. A "Mock-up" welding torch is tracked by cameras. The robot arm on the welding system moves the heavy duty welding torch identically to every movement of the mock-up torch.



Feedback is provided to the operator via a VR screen (A) and a ultra-high dynamic range camera image of the welding process (B). The skilled human welder uses the VR Cell to control the VR Controlled Mobile Robot which is doing actual welding at a remote location. The welding robot can be remoted up to several hundred miles away from the VR Cell (has been demonstrated making welds 800 miles distant from the human in the VR Cell).

A mobile VR Cell can be mounted on a large ATV (see John Deere Gator – left).

That cell can also be equipped to be wheelchair accessible to provide employment for people who, otherwise, might not be able to work in the field, at remote job sites.



The VR Controlled Mobile Robot can make high quality welds. The system can also carry a heavy machine welding torch that weighs to much for a human welder to carry around during an entire shift. This extends the ability of an expert human welder to be able to make welds without the need for expensive scaffolding, and be up to 4X more productive (i.e., total number of feet of weld produced per day).

Information:
EnergynTech, Inc., 11354 W. 13th Ave., Lakewood, CO 80215
Jerry E. Jones – 720-232-34390