LOW-FORCE HIGH-ACCURACY FOLDING & BENDING BY HAND

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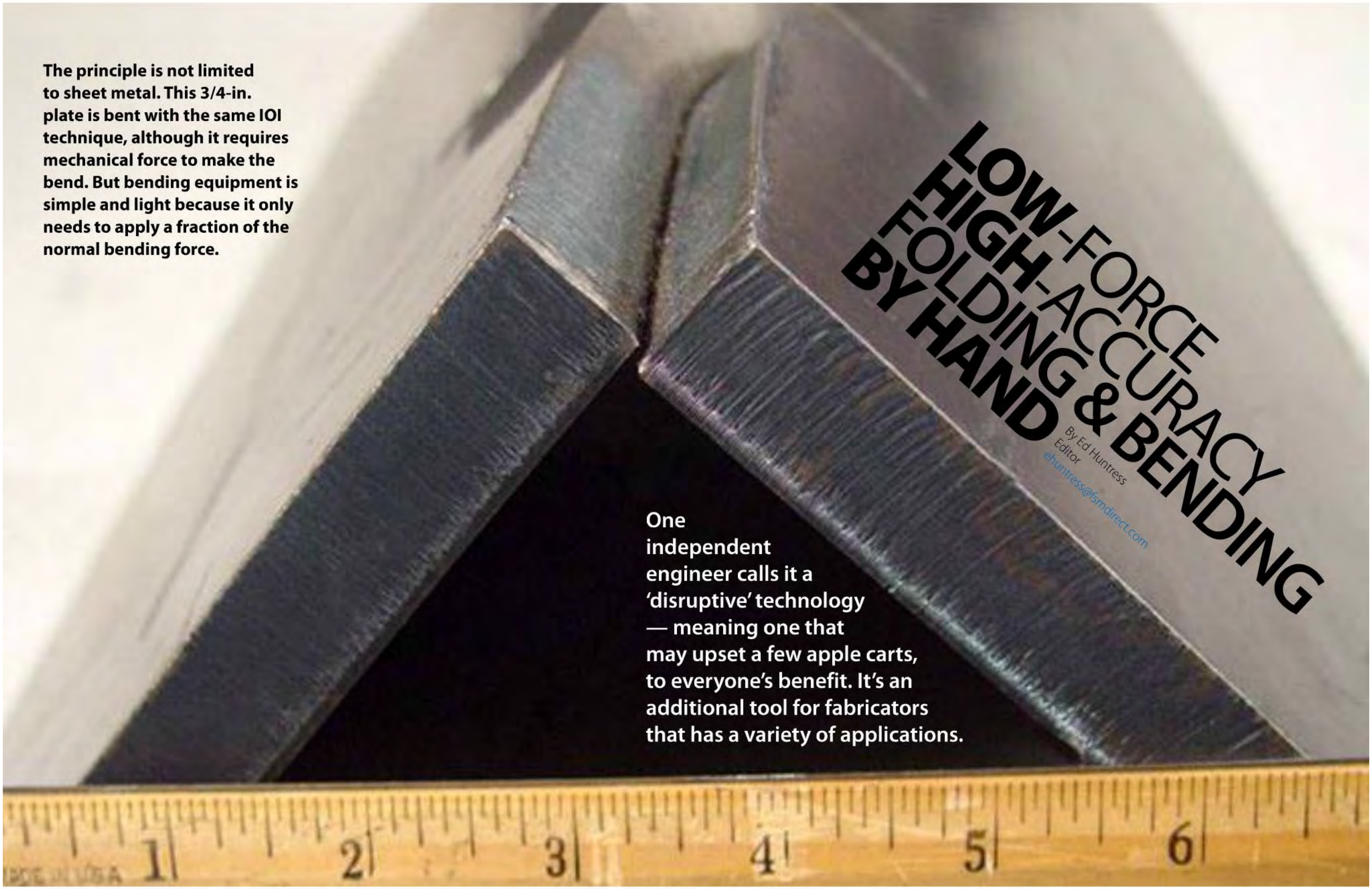


The principle is not limited to sheet metal. This 3/4-in. plate is bent with the same IOI technique, although it requires mechanical force to make the bend. But bending equipment is simple and light because it only needs to apply a fraction of the normal bending force.

One independent engineer calls it a 'disruptive' technology — meaning one that may upset a few apple carts, to everyone's benefit. It's an additional tool for fabricators that has a variety of applications.

If you watched the video on this month's cover, you saw the reason that this folding technology stopped us dead in our tracks – "Look ma, no press brake." And that isn't shim stock they're folding. Some of the parts for this project are made from aluminum up to 5 mm thick (that's not a typo) and they're being folded by hand as well. That is, with a gang of eight college students doing the folding on the 5 mm-thick parts.

The part in the video is a battery box for Clemson University's Deep Orange car-engineering project. The folding technique is used widely throughout the car's structure; the entire assembly of boxes and shear panels, which make up the lower part of the car chassis, was folded by hand. Bonded with adhesives and rivets, the structures are up to handling a car's abrupt and repetitive dynamic loads, and they're stiff. Even the strut towers, which are severely loaded where the top of the strut connects to the chassis, are made by hand-folding, adhesive-bonding, and riveting sheet aluminum.

Both a production and a prototyping technology

The technology is called "Industrial Origami," patented and developed by a company of the same name. It is not just a one-off and prototyping method: Industrial Origami's customers are making thousands of parts in some cases. And they aren't always folded by hand. Simple low-force pneumatic machines are folding parts in production.

The Deep Orange project, or projects, because they've produced a series of cars, are not exercises in custom car building. They're development projects for engineering production cars. Mazda is involved with this one (the photos are of Deep Orange 3; there are more on the way). The finished car adopts the "multi-material" design philosophy that Clemson's Dr. Paul Venhovens sees as the near-to-medium-term future for car manufacturing: aluminum, some carbon fiber and other composites, a bit of high-strength steel, bonded, riveted, and welded together. As CAFE requirements prod the engineering of more efficient cars, "lightweighting" is as important as improving drivetrain efficiency.

So the aluminum box-and-panel structures are serious production ideas. But Clemson doesn't have a press brake.

A hybrid structure of aluminum torque boxes, shear panels and tubes, Deep Orange 3's chassis/frame is advanced and lightweight. The entire sheet structure was hand-folded.

Clemson's Deep Orange 3 is a serious engineering development project that has won engineering awards and industry attention. It's an attractive, functional car. The body is fiberglass, and not a stressed part of the frame structure, as a practical matter for a one-off project.

Enter Industrial Origami, Inc. (IOI).

Hole accuracy even after multiple folds
"We're always looking into reducing capital investments in the manufacture of automobiles. Of course, for a one-off prototype, we couldn't afford conventional tooling," says Venhovens.

And the no-tooling IOI technology provided more than easy bending. It's also extremely accurate. "No jigs were needed to line the parts up. We had rivet holes laser-cut on the flat sheets and folded them until we had three overlapping layers to rivet," says Venhovens. The rivets went right in.

IOI says that they've riveted folded structures with up to eight layers of sheet metal. Tolerances don't stack up. The folds occur exactly where they're supposed to and the bend allowances are consistent and predictable. "The folds occur where you plan them, laid out on the flat sheet," says IOI's Bernie Mabrey, Dir. of Business Development.

The concept is simple, and it's implemented in a couple of different ways. In one method, used in Clemson's project, intermittent laser cuts are made in crescent shapes (IOI calls them "smiles"), leaving uncut, angular sections in between the cuts. They call these "straps." This reduces the bending force and controls the exact location of the bend. "So if you lay the pattern in a straight line, it will fold in a straight line. If you lay the pattern in a curve, the metal will fold in a curve. It doesn't have any choice," Mabrey explains.

You control the amount of bending force required by programming the relative lengths of the cuts and the straps. As an alternative to the laser cuts, the cuts can also be made by punching with a lance-type punch through the sheet, in a series along the line to be bent. This method is more suited to production than to prototyping. IOI has several techniques that produce different strengths and cosmetic effects.

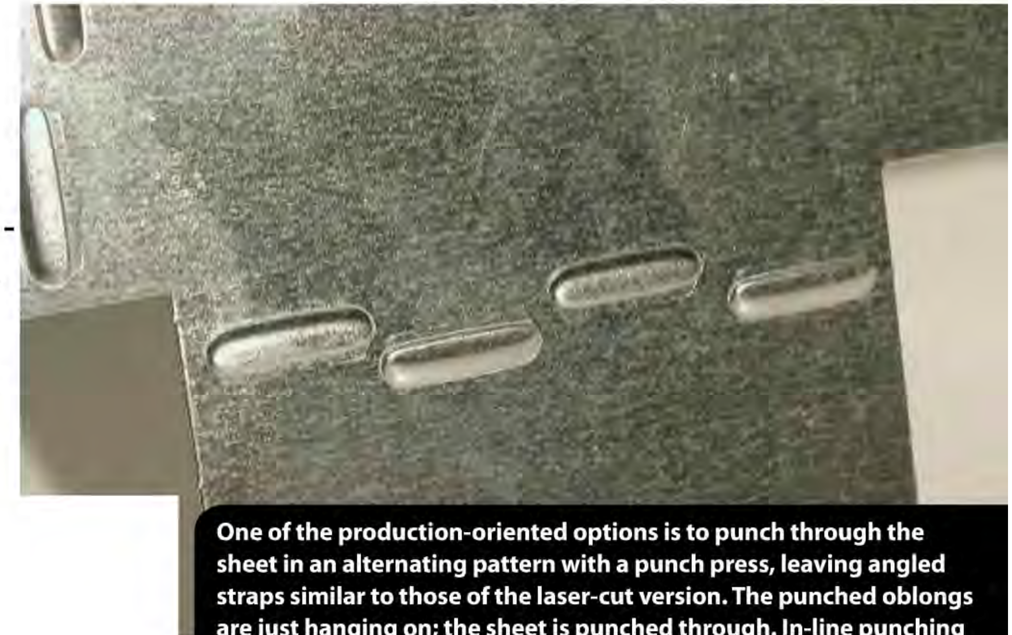
Folds are like hinges that can be rigidly secured
"You can think of them as hinges," says Kevin Walz, IOI's VP of Sales and Marketing. "If you don't secure the free edge, it will come open under force. One way you can secure the folds is by creating overlapping flanges, and

welding, adhesive-bonding, or riveting them. Another thing you can do is to create "spring-clip" features in the cutting program. Because of the great accuracy of the process, you can have a male and female clasp, where the metal simply connects to itself."

Like a cardboard carton, the inherent strength of one of these structures comes from closing a box, or from arranging panels so they're stressed in shear. If greater stiffness or strength is required of the "hinges," the methods that Walz describes will secure and reinforce the folds. One way to think about the strength properties, he says, is that the straps occur with the approximate frequency of spot welds in an edge-welded assembly, but with the advantage that the joints are in the parent metal. In most cases, the stiffness inherent in closed sections secures the intermittently-cut folds with more than adequate strength. And the exceptional accuracy of multiple-layer hole locations makes it simple to arrange a rivet, a bolt, or other fastener to secure panels to each other between the folds.

The patents, and the subtle engineering, are implemented in IOI's software. The laser-cut shapes produce an angular bend in the straps – they don't fold straight across. The result is less stretching of the metal in the straps than would occur with straight-across folds, and a more predictable fold location.

IOI has produced databases of material types, thicknesses, and bend allowances, and how they will bend when cut or punched with their processes. But a user doesn't need the databases: IOI will supply the data for a small number of materials, as they did for Clemson's car project. "All you need is a DXF file of the part. And the productivity programs are run in Pro-E," says Walz.



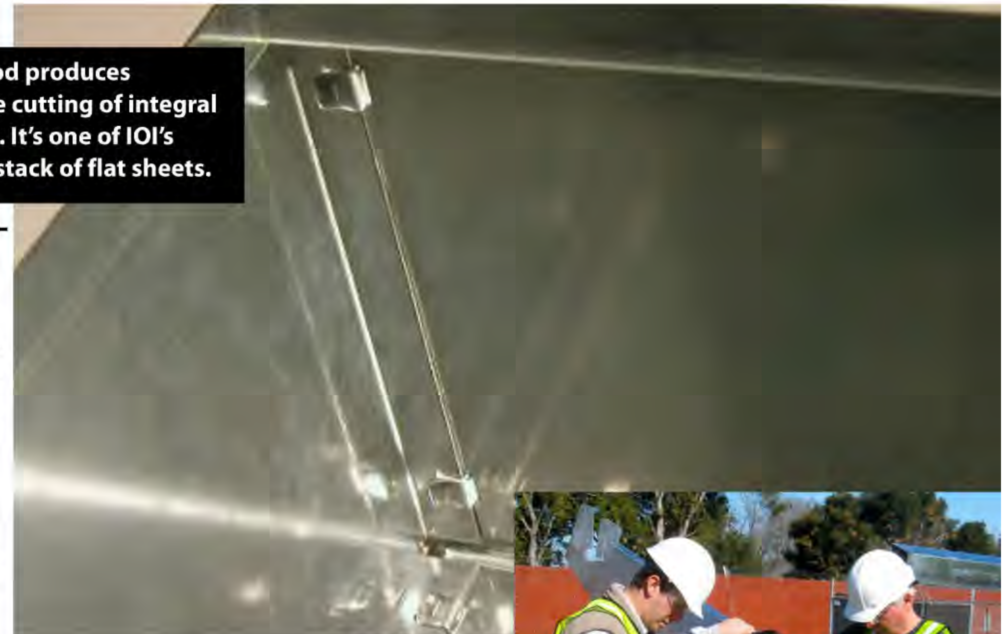
One of the production-oriented options is to punch through the sheet in an alternating pattern with a punch press, leaving angled straps similar to those of the laser-cut version. The punched oblongs are just hanging on; the sheet is punched through. In-line punching is used where a more cosmetic outside appearance is called for.

Laser-cut 'smiles' (and frowns?) are the heart of the prototyping and short-run version of IOI's technology. Between the cuts, intact 'straps' bend on an angle, reducing stretching and contributing to the accuracy of the fold.

The key is knowing where to cut

In other words, IOI's product is not the cutting of metal; it's knowing where to cut. The technology involved is simple to implement. In Clemson's case, students designed the assemblies in SolidWorks, they were run through IOI's routines, and a job shop made the laser cuts. Only a couple of parts didn't work the first time, which Venhovens attributes to students' calculation mistakes.

Clemson's car project is a dramatic example of the prototyping capability of IOI's process, but the company has made inroads in several targeted



The accuracy and consistency of the folding method produces reliable rivet-hole alignment, or, as in this case, the cutting of integral 'spring clips' that close the assembly without tools. It's one of IOI's techniques that allow for on-site assembly from a stack of flat sheets.

production markets as well. A key one is the solar-power industry, for which they've designed a fixed-tilt ground-mount solar rack with boxed columns, support structure for panels, and other components. Other markets include consumer appliances, furniture, electrical enclosures, and agricultural and construction equipment. For the latter, the thickness capability of the process gets a good demonstration – see the 3/4-in. plate photo, folded with the same technique as appliance-enclosure sheet metal. Simple powered folders handle the thick material, requiring only a fraction of the force that would be needed to bend solid plate.

The IOI technique suggests other opportunities for fabricators, not as a direct replacement for conventional methods, but as a door-opening approach to design and build products with fewer components. Many structures can be folded and assembled on-site from pre-cut sheet, which allows them to be shipped flat and compactly inventoried.

Because manual folding makes it easier to reach into and fold complex geometry, one of the greatest advantages of Industrial Origami is the ability to make structures with fewer parts. "We're much better at assemblies than at part replacements," says Mabrey. "The first thing we'll ask is what the part is attached to. We might turn five parts into three."

A new tool for your toolbox

It's a new tool for the fabricator's toolbox. IOI's Mabrey says, "I would only consider using us if you wanted to save time, money, and headaches."

Tour the company's website to see other application ideas and examples. Their site is well-packed with videos and photos of products being made in production with IOI's methods.

And don't miss the story behind Clemson's Deep Orange car projects. Winners of several engineering awards, they illustrate what manufacturing engineering education can be. These are not students' impractical dream projects. They're serious prototypes for design and manufacturing. They illustrate the use of this manual folding technology in advanced structural design for a very demanding application.

And the cars look great. ⚙

Industrial Origami, Inc.

Clemson University's Deep Orange project

Photos of Deep Orange 3

IOI recognized a market opportunity in the solar-power industry, for which they designed a field-assembled galvanized-sheet support rack. Their low-force folding technology is used throughout.