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Plasma Beveling Technology Offers Precise Plate Weld Preparation

In a recent cooperative experiment between Canadian and Australian companies, engineers ran two tests of precision plate weld preparation attaching a new three-axis (ACZ) plasma bevel head to a conventional XY plate profiler to create a synchronous five-axis plasma profiler. The core question was whether the new-generation plasma torches combined with the latest many axis controls were capable of producing multi-face beveled edges of sufficient accuracy for practical weld preparation.

Numerically controlled (NC) plate beveling machines have been in the marketplace for 30 years. However, their population is less than 0.5% of the approximately 200,000 machines worldwide. Therefore, plate weld preparation remains as it has always been, a shop problem, and almost all plate steel is square cut except for shipbuilding and, lately, for windtowers. So despite massive advances in welding technology over the years, the required weld preparation is still a semi-manual process: slow, dirty, demanding, costly, and requiring skilled operators. With an aging workforce, this is a serious problem for maintaining core capacities in heavy engineering.

The quest was whether we could precision cut K bevels in weld-ready parts with an NC plasma torch to an accuracy of ± 1 mm. To do this, three passes were used — Fig. 1.

Many specific innovations were also being tested including a distance measuring laser for torch height, three digital servos inside a pantograph bevel head, and a series of mathematical modules to calculate positions and compensations in real time. The pantograph design eliminates errors from torch rotation. The patent-pending plate scanning device removes height errors from traditional arc voltage height control.

Numerical control plate profilers have only two axes, X and Y. Beveling machines add torch tilt (A), the plane of torch tilt (C), and there is usually a torch lift Z axis. While this looks like five axes, in almost all machines the C is kept square to the XY path in a method called tangential following so it is a dependent axis. In a legacy concept from the 1980s, torch height or Z is not programmable but driven by an independent torch height control. Lastly, the torch-tilt axis is generally not able to be interpolated with the XY axes. So most existing beveling machines have only 2½ simultaneous interpolated axes, which is very limiting, and you cannot get bevels into the inside corners or notches. To create sharp outside corners, this means large loops are required, which waste plate and make three-pass weld preparation impossible.

In contrast, in the two tests conducted, five simultaneous axes were used: X, Y, A, C, and Z. The complex and coupled tilt and twist axes in the pantograph design were derived with real-time computation from the programmed axes A and C.

A further critical restriction in most existing machines is that torch tilt is generally limited to 45 deg. This is actually a severe limitation, which can leave as much as half the material removal to be finished by hand. For example, to create sharp corners without loops, the torch needed to tilt much further for the large groove angles in Test 2.

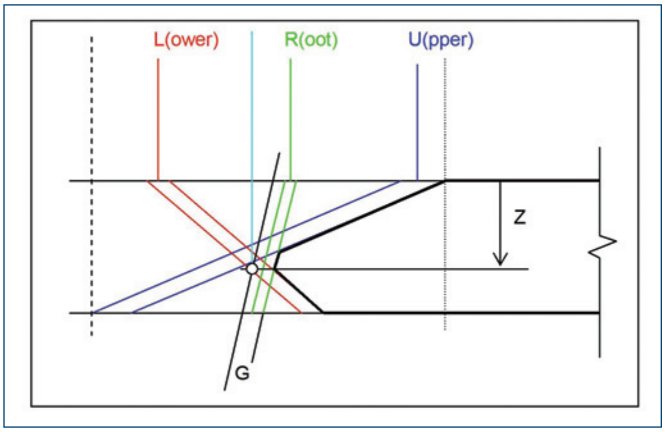

Fig. 1 — Weld preparation with three passes of the plasma torch.

The test can be seen on www.youtube.com/user/FastCAMService/. Much of the software technology is invisible in the video and beyond the scope of this article. A new entirely mathematical approach was developed to generate torch position, varying feed, and kerf and torch angles both in the generation of the NC and in the control itself. This was based on the assumption that the modern plasma arc could be modeled as a cylinder with diameter dependent only on effective material thickness and feed rate. Finally, and unlike other systems, no empirically derived tables were used for the many offsets involved.

The two tests required similar K bevels on small parts about 300 × 200 × 25 mm thick. The 5-mm-deep weld face was vertical in the first test and rolling in the second, simulating the developed edge of an oblique cut through a pipe. Grooves were at a constant 30 deg relative to the weld root face angle.

In each test, the bottom pass was cut first, then the center pass, and finally the top pass to minimize the effect of previous cuts. To achieve the sharp corners in Test 1, there are stationary points where only the two rotary axes A and C move with no XY movement. Industry opinion was that this would not work. The quality of the cut was also quite unknown as the feed rate varies along the length of the arc itself. Other sections require four simultaneous axis movements X-Y and A-C. The torch tilt had to increase smoothly from 30 to 39.2 deg and return while moving and cutting. Z movement over these distances is tiny.

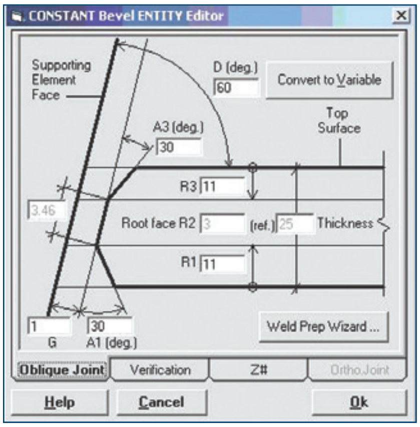

Fig. 2 — Constant dihedral weld data collection.

In the earliest tests, it was unknown whether the V-shaped scrap between the first and second passes would drop and block the third pass, the part move between passes, the corners melt away, and the arc stay cutting when the machine was not actually moving. Even successful crossing of existing cut paths was unknown let alone part tolerances and quality. Dross was a concern as was the path of the plasma beam when additional pathways were available for the plasma stream. Splitting and curvature of the beam were possibilities.

Close examination of the finished parts indicated very acceptable quality, straight cuts, and size and edge profiles within tolerances at cuts up to 55 deg.

The Bevel Editor. Not shown in the videos is that the three-pass NC programs were created from the CAM file without explicit NC programming. In the patent-pending concept, 3D CAM parts are completely defined by a welding professional including all weld preparation.

The CAM files remain 2-D in nature with parameterization on each geometric entity to enable the recreation of the 3-D part. The files at this point are independent of the cutting process.

To create these files, a separate piece of software called Bevel Editor is needed. It is the intention of FastCAM, Inc., to make Bevel Editor free to welding professionals.

At the production site, the files are nested onto a plate for a specific machine and cutting technology. It is only then that part geometry is translated into multiple passes on the top of the plate. The machine-specific NC code is generated automatically with all the compensations, offsets, passes, and corners in place. With this approach, there is also no practical difference between nesting and cutting weld-ready parts and traditional square cut parts allowing a smooth transition to the new technologies.

The essence of Bevel Editor is a data entry form to define a weld preparation on a single edge. This is shown in cross section in Fig. 2 for the simple case of an edge along which the K preparation is constant.

The angle D is the local dihedral angle relevant to welding the upper groove. The default is 90 deg, which is common for an orthogonal T joint. For butt joints, the equivalent or notional supporting element face is simply the bisector of the butt joint and the groove angles and root opening can be halved. Note that such direct NC programming systems as exist require D = 90 deg at all times, which severely restricts their usefulness.

D is an intrinsic property of the assembly before weld preparation. It is not directly a welding parameter. Rather, it can be defined with no knowledge of what joint technology will ultimately be applied. While it is seldom defined on individual part drawings, it should always be derivable from the assembly.

The remaining parameters G, A1, R1, A3, and R3 are all weld prep parameters and can be varied to define single and double bevel or V grooves, with or without a finite root face depth. This is equally relevant for complete-joint-penetration (CJP) and partial-joint-penetration (PJP) applications.

Plan Dimensions. If the weld root face is not vertical (D other than 90 deg), a critical issue is how the plan view part drawing has been dimensioned. With weld preparation, the parts are now 3-D. The common choices with our categorization are shown in Fig. 3.

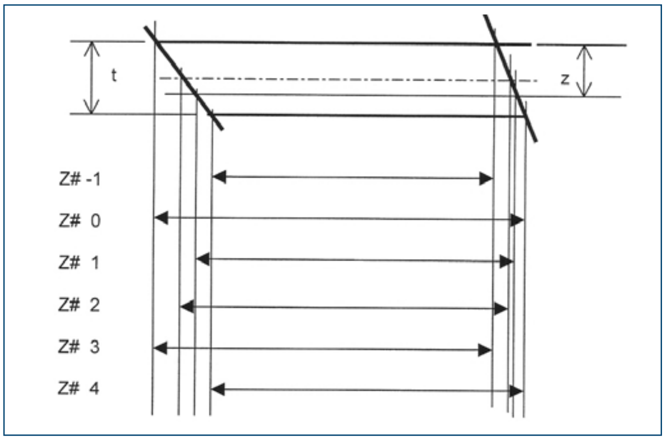

Fig. 3 — Common methods for dimensioning flat plates with dihedral cuts.

- Z#0 is the most common in practice. When parts are square cut on all edges, it guarantees sufficient material for weld preps to be applied using secondary processing techniques.
- Z#-1 is the exact converse of Z#0 and has the advantage that parts can be assembled prior to any secondary processing, provided that secondary processing can be undertaken in-situ.
- Z#2 is most commonly applied to parts that are developed by triangulation.
- Z#1 is often encountered at butt joints between parts of unequal thickness.

Z#0 has become a de facto standard, and many NC systems require that all parts be redrawn. Then, NC controls have to project the movements to the top surface and attempt to solve the path discontinuity problems. In our approach, there is no need to redraw parts. It is only necessary to categorize the dimensioning method used, and no change is required in shop detailing practices.

Varying Bevel Editor. Curved plate work is based on the same principles but is typically more complex. Given the large angle variation, the type of weld preparation can actually often vary along a single edge.

In Test 2, the initial CAM file was created with software that defined the shape of the edge by its X, Y values plus the dihedral angle D at each vertex, and Z# for the edge. Had these data been supplied via a file from a general design system, the Z# and D would need to be determined and D entered manually at a sufficient number of points along the edge to satisfactorily represent the rolling dihedral edge. Bevel Editor is changed to a spreadsheet-style format for this purpose, and will calculate all intermediate D values in a vertex table using edge-length based linear interpolation.

Additional Software. The type of weld chosen is based on many factors including access, equipment, skills, time, location, and, ultimately, cost, which can vary greatly. Within Bevel Editor, Weld Prep Wizard (WPW) provides a rational decision framework for specifying and then costing a variety of preapproved weld preparations for a particular joint detail.

The logic is based on a tabulation of permissible weld prep details for ranges of dihedral angle. It can include a fabricator's own WPS library details plus prequalified details from any number of welding standards including AWS D1.1, *Structural Welding Code — Steel*. A simple costing model is used.

The WPW decision framework covers the following stages:
- Joint arrangement: T, butt, corner bevel, corner V
- Joint type: Complete penetration groove, partial penetration groove, or fillet

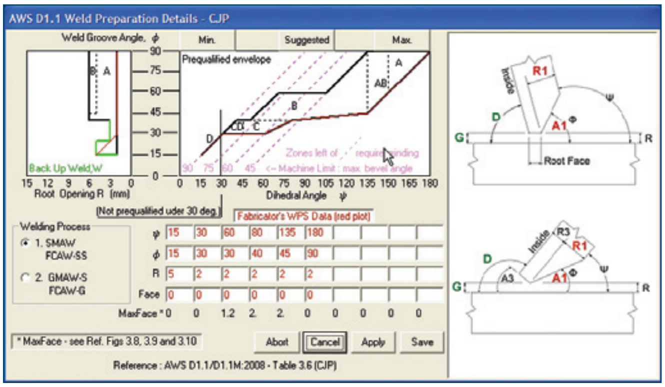

Fig. 4 — Tabular CJP provisions of AWS D1.1, Structural Welding Code — Steel*, as used in the weld editor.*

- Welding process: Shielded metal arc, submerged arc, flux cored arc welding, etc. (definable in costing model)
- Backing: Usage, location, removal requirement
- Access: Top, bottom, both
- Position: All, flat, horizontal, vertical, overhead — per side.

Given all applicable data, WPW presents all viable options in a table ranked by cost.

One characteristic of such joints is potential for an extreme range of dihedral angles. The CJP provisions of AWS D1.1 can be summarized in chart form as shown in Fig. 4.

Large tubular members are normally developed inside-up ready for forming, so the external local dihedral angle for welding, Ψ, translates to a beveling dihedral angle D = 180 – Ψ, while the groove angle, Φ, equates with the parameter A1 at the underside of the plate.

The diagram plots an envelope of the range of groove angles prequalified for a given local dihedral angle, which are actually defined vice versa in AWS D1.1:2008 Table 3.6. The zones labeled A...D correspond with the detail diagrams drawn in AWS D1.1 Figs. 3.8–3.10. The dashed lines represent the effects of tilt limits. The importance of a 60-deg tilt limit is the dihedral can go as low as 60 with a much reduced groove angle of 30.

The left area plots prequalified ranges of root openings for various groove angles. The table in red represents data from the fabricator's WPS library, which is plotted in red on the diagrams above the table for ready reference. This diagram is for complete joint penetration.

Once the choices are made, the WPW fills the vertex table with weld prep parameters for every dihedral angle D, the parameters being interpolated from the tabulated data in the relevant chart.

Information Transfer. Five-axis NC milling has had the ability to transfer 3-D parts electronically for immediate and accurate manufacture for some years, a simplicity that has been denied plate fabricators because of their additional requirement to nest parts onto flat plate. FastCAM's patent-pending invention achieves a similar facility for parts with weld preparation. The key concept is that the CAM file remains a 2-D file for the purpose of nesting but contains parametric description of the finished 3-D part. These parts then can be nested in a modified, but largely conventional, nesting system and mixed freely with square-cut parts and with precise clearances.

What's Next

With the availability of the new technology, the authors expect to see a rapid change to precision weld preparation instead of just square cutting of plate. The technology adds little cost, but offers opportunities for cost savings and gains in productivity. The benefits take on greater significance because of the expected reductions in skilled shop labor. Very quickly, whether in house or through service centers, fabricators will demand weld-ready parts not raw shapes. These experiments have shown that precision automatic weld preparation is now possible on plate without the need for hand grinding. ◆

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