Optimisation of flat pattern shapes for aerospace sheet metal parts

Kawasaki Heavy Industries, Tokyo, Japan and Mike Lee, Hexagon's Manufacturing Intelligence Division in Canada

Kawasaki Heavy Industries accelerates the flat pattern development process and reduces the number of tryout iterations to develop parts first time right using FormingSuite Advanced.

Kawasaki Heavy Industries (KHI) is a multi-national corporation with more than fifty holdings (manufacturing plants, distributions centres, and marketing and sales headquarters) in most major cities around the world. Business interests include environmental control and energy plant engineering, machinery and robotics, ship building and marine engineering, power plant engineering and steel structures, rolling stock, aerospace, and of course, ATVs, motorcycles, side-by-side vehicles, and personal watercraft.

In general industry, there are various sheet metal processing methods, such as stamping, brake press, and spin processing. Among these, the complicated high-volume shapes such as automotive parts will often use the punch and die method to press the material and form it into the desired shape.

By holding the excess material well, not only can it form the material, but it can also draw or extrude the material. The tooling can also be designed to incorporate in-process trimming operations to create the correct part boundaries.

On the other hand, in the aerospace industry, due to its low volume and product variety, instead of using expensive press forming, the bladder forming process is often used. This process only uses the lower die to form the part. In the bladder forming process, it is common to stamp components from fully developed (aka net shape) flat patterns such that no trimming is required after forming.

However, with this method, it is difficult to create a developed shape that correctly accounts for the elongation

and shrinkage the material undergoes during forming. Flat patterns developed via empirical measurements of part geometry often produce resulting parts that do not match to the 3D part geometry. Furthermore, for parts with a double-curved surface, it is impossible to simply “unfold” them and therefore they require further processing after forming. Due to these issues, KHI could not take full advantage of the bladder forming method.

Several years ago, KHI introduced Inverse Finite Element Method (FEM) technology to create the developed shape and have made significant achievements. One such achievement was greatly improving the geometric accuracy of the final part after stamping. Moreover, by using this technology, it is possible to apply Hole to Hole technology by piercing holes before the forming process while maintaining accurate locations on the final three-dimensional geometry.

About the process of bladder forming and developed shape

Figure 1 shows the outline of the bladder forming process equipment. This processing method is often classified as hydraulic forming (hydro forming) or rubber pressure forming and consists of a pressurised cylinder filled with a rubber balloon called a fluid cell. This rubber balloon expands due to hydraulic pressure, becoming a substitute for the upper die. It will push material placed on the lower die so that it wraps or forms around the lower die to produce the shape. This forming process is shown in Figure 2.

Problems with the conventional deployed shape

In the bladder forming process, in many cases, fully developed blank shapes are stamped on a flat surface. For this reason, in the developed shape, it is necessary that the end of the part coincides with the design requirement. The design requirement is the position of the three-dimensional CAD after stamping.

In the past, there was also a concept that "As formed is OK" if the provided flat pattern was used for forming. However, as three-dimensional CAD is becoming more common, this way of thinking is no longer acceptable. The part must now be "as designed" by the three-dimensional shape. This means that the drawing / production to predict the accurate developed shape that will form the part is essential. Using geometrical development software for unfolding, along with experience-based approaches were not sufficient for accurately predicting development of complex shapes within the required tolerances.

KHI also thought to estimate elongation / shrinkage by classifying each component shape and formalising it by subdividing it, but it was necessary to divide the parts into many cases and it was not realistic. In addition, the components of complicated shape eventually depend on the knowledge level of the creator of the drawing, and it took several hours to create the developed shape at the present time. Developing the shape of more complicated parts relies on trial and error, and in the case of a shape having extreme shrinkage (or elongation) as shown in Figure 3, it was obvious that it can't be formed to the part shape from the geometric developed shape.

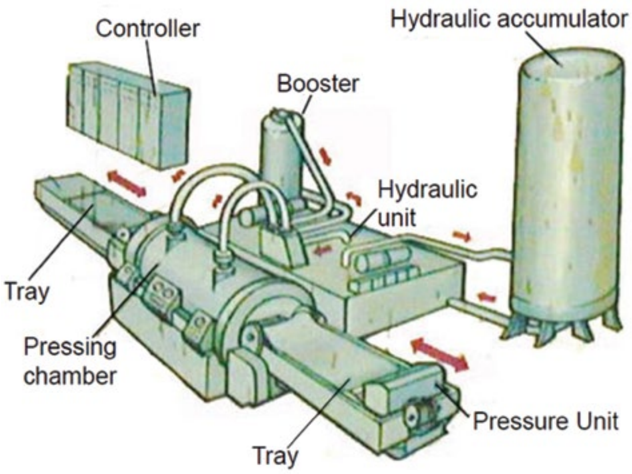

Figure 1: Hydraulic rubber pad press (Bladder forming)

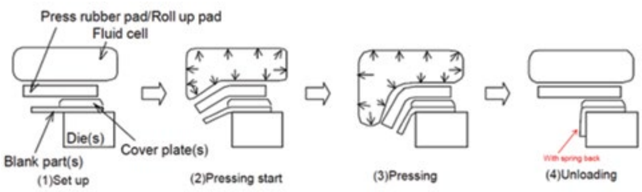

Figure 2: Bladder forming process

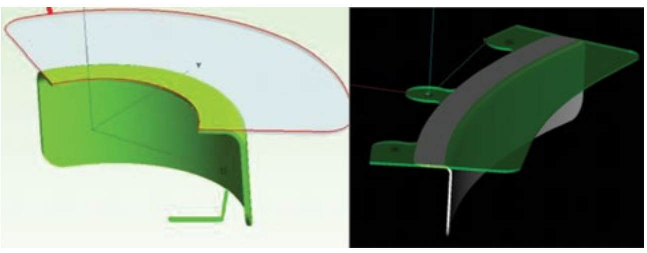

Figure 3: Extreme case outer boundary geometry blank unfolding

New developed shape creation method

From the above background and problems, KHI decided to create a developed shape using the Inverse Finite Element Method (FEM). In this method, since the material is solved in one step, assuming that the material adopts a linear strain path, ignoring the history of deformation, it will have an extremely short calculation time. Furthermore, since it is an inverse solution that solves the deformation process in the opposite direction from the product shape to the developed blank, tooling information is unnecessary in the simulation and it is extremely convenient to handle.

Mainly used by automotive manufacturers for trial analysis such as formability studies before detailed incremental simulation, but due to the nature of the calculation method, it is an optimal method to create the developed flat patterns for these parts. For the Inverse FEM solver, FormingSuite 3D (now called FormingSuite Advanced) was used.

Next, some practical examples of improving developed blank accuracy by Inverse FEM, will be introduced. All the test materials were the materials specified in the drawing. Also, from the stress strain curve obtained by a tensile test, the result identified by the N-th power hardening rule were used in the finite element model. The stress-strain diagram obtained by the tensile test could be directly imported into FormingSuite Advanced. The pressure of the pressure pad was set as the pressure applied by the actual device.

Part with a shrink flange

Figure 4 shows a shape developed by a conventional method for a part having a flange to be shrunk, and Figure 5 shows the same part after stamping having a shape developed according to the newer technology. In the conventional development method, the actual product end (EOP, Edge of the part) was shifted by 3.3 mm from the position on the CAD by a maximum of 3.3 mm, but at the maximum in the shape obtained by Inverse FEM it was a difference of only 0.12 mm. Although a part with a compression (shrink) flange is shown as a representative example, the accuracy was also improved similarly in the case of the stretch flange. For any part, the accuracy improvement of at least 3 to 4 times (mismatch amount ⅓ or less) was achieved.

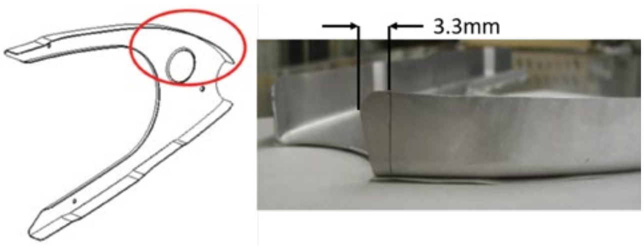

Figure 4: Conventional flat pattern method

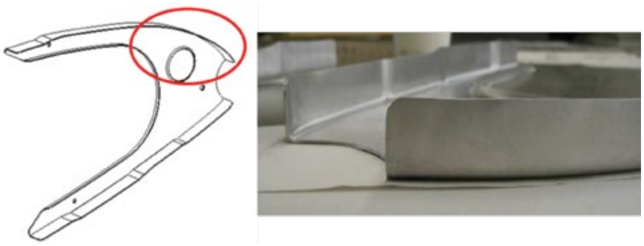

Figure 5: One step FEM flat pattern method

Part with joggle

For components with joggles, since expansion and contraction occur just below the joggle, it is difficult to predict the developed shape. In the past, it depended on the design process such as making the developed drawing with a shape that is smoothly connected empirically and using it as it is after stamping.

As shown in Figure 6, it was confirmed that the parts manufactured from the shape developed by Inverse FEM have dimensions as specified by 3D CAD even at the flange immediately below the joggle.

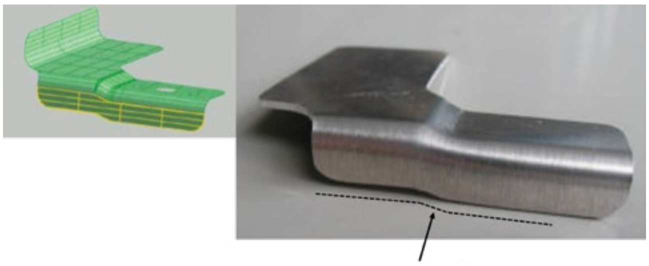

Figure 6: Comparison between FEM flat pattern and 3D CAD

The creation of the developed shape by Inverse FEM is effective not only for the bladder forming process but also for other typical manufacturing methods for aircraft.

Peen forming

It is also applicable to the developed shape of the peen forming parts such as the main wing. The developed shape and the main strain during stamping are shown in Figure 7. Although this part was a part with a kink in the centre region, it was possible to create a developed shape such that the part and Edge of Part (EOP) after stamping matches the CAD accurately.

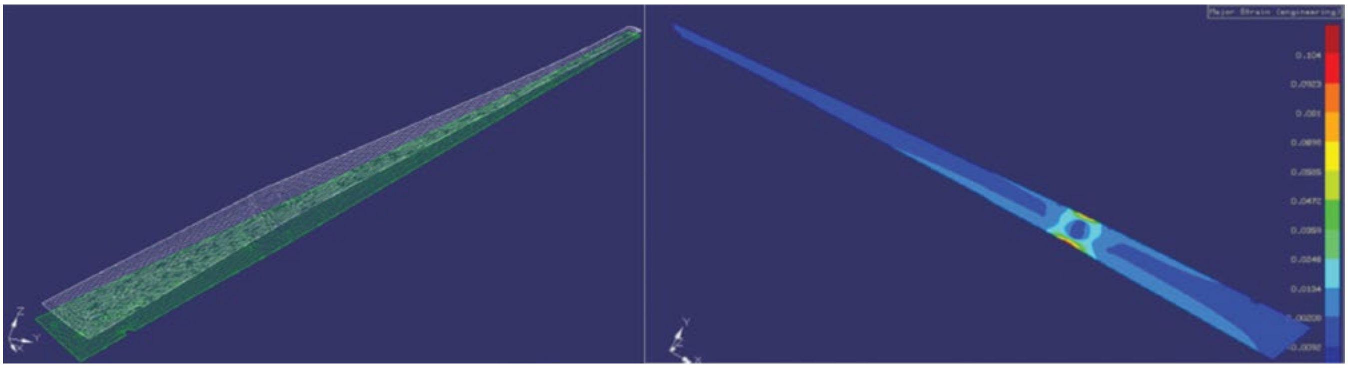

Figure 7: Application of 10m Peen forming

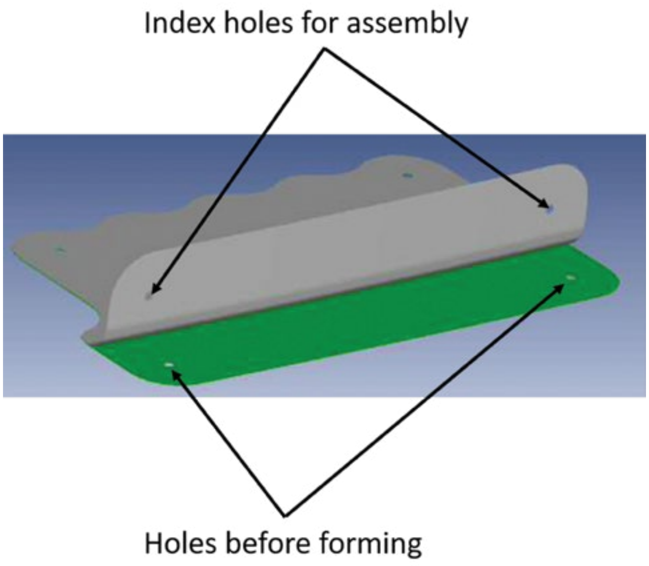

Figure 8: Application of press stamped shear tie

"It has become possible to develop even parts of complicated shape which could not be developed using conventional methods ..."

Flat pattern drilling on stamped parts

In order to perform the hole reference assembly, precise hole positions are required. Precision is required so that in the case of sheet metal parts, particularly parts providing hole standards on the stamping surface, drilling using a jig was performed after stamping.

In One Step Inverse FEM, not only the EOP of the part but also the hole shape on the stamping surface is developed in the flat pattern. This way it can be confirmed whether the hole is collapsed, by modelling it including the hole. On the other hand, by using the software, we were able to improve it so that we could map only the hole position centre on the element. As described above, regardless of the size of the hole, it was possible to reflect the hole position in the developed shape by Inverse FEM.

If the hole after stamping is placed at a position where the hole reference assembly is sufficiently filled, drilling is performed at the same time as the outer periphery of the part NC trimming in the flat state, so that no drill jig or drilling step is required. With such a hole reference assembly, it is possible to contribute to cost reduction not only in the reduction of the component process but also in the assembly process even in the sheet metal component.

Figure 8 shows the developed shape of a press stamped shear tie. Compared with the development of the conventional method, it was also confirmed that the hole position accuracy by this method is improved like the EOP.

Summary

The following results were derived by using Inverse FEM for creating the developed shape.

By using the inverse FEM method, the developed shape accuracy was improved. The accuracy was improved more than three times as compared with the conventional method. "In our company, defects due to errors in the developed blank shape are drastically reduced, and the time taken to produce the developed shape has also decreased compared with the conventional method" says Hideki Okada, Senior Staff officer. Furthermore, "it has become possible to develop even parts of complicated shape which could not be developed using conventional methods, making it possible to apply the bladder forming process together with the spring back prediction technology" adds Okada.

It is effective for other major processing methods in aircraft, such as peen forming, roll forming, drop forming and stamping (pressing).

Finally, it is possible to accurately reflect the hole position in the developed shape, and it is also effective for application to hole reference assembly methods.