Technical Paper

Production Technology of ROPS Cab

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Rollover is responsible for many of the operator accidents of hydraulic excavators. Protection of operators during rollover is very important and a structure that significantly increases the cab strength has been required also for Komatsu to install a cab that meets the Rollover Protective Structure (ROPS) safety standard. This will increase the machine weight and manufacturing cost due to a change in the manufacturing method. This paper describes the production technology developed involving simultaneous actions in the design phase and all processes (from material processing to the finishing process) to build a cost-minimal production system in order to overcome these disadvantages.

Key Words: *Cab, ROPS, Simultaneous actions, High-accuracy temporary assembly, Automated welding, Searchless welding, Visualization*

1. Introduction

Safety regulations on the structure of cabs to protect the operator in rollover have been in place for bulldozers and other machines from early on. In March 2003, the Japan Construction Mechanization Association (JCMAS) established safety regulations also on hydraulic excavators, followed by the International Organization for Standardization (ISO) in December 2008. Komatsu has had to comply with these regulations. In cooperation with our design and purchasing departments, a structure and production system meeting the standards were built, as reported hereunder.

Fig. 1 Crash-safe body

Fig. 2 Machine tipping test

2. Cab New Structure

A cab with a Roll Over Protection Structure (ROPS) is required to be seven times stronger than a conventional cab and thus dramatic modification is needed. The structure was changed from a sheet-metal spot welding structure in the past to an arc welding structure built on steel pipes as a framework. Both the weight and amount of weld deposition significantly increased (**Figs. 3, 4**).

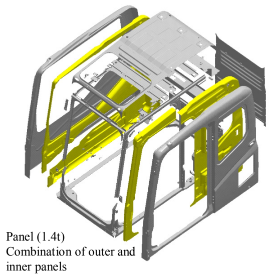


Fig. 3 Conventional structure

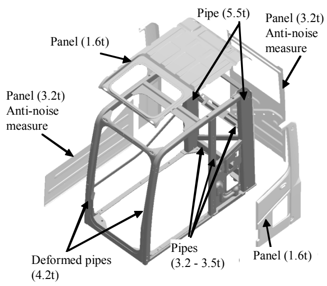


Fig. 4 ROPS structure

In the conventional ROPS, safety during rolling over is secured by its framework of pipes and the panels were added to ensure cosmetic appeal. Almost all of the panels were directly mounted onto the framework and almost all of the welded locations were made visible to allow lap welding and fillet welding.

3. Development Targets and Production Technology Problems

A cost increase was expected due to the addition of the foregoing functions and a minimum cost production system encompassing (from material processing to the finishing process) was set as a target. The target values for the target items are given in **Table 1**.

Table 1 Development targets

Process	Member	Aim	Target
Materials	Panels	Lower material grade	Material SPCC
		Blanking process discontinued	Discontinued
	Pipe	High-accuracy bending	Flatness 2mm or less
		High-accuracy 3D cutting	Clearance 1mm or les
Welding	Framework	High-accuracy temporary assembly system	Clearance 1mm or les
		100% automated welding	100% automated
		Searchless welding	100% searchless welding
Finish	Framework	Excessive finish discontinued	Discontinued

4. Development Work

4.1 Raw materials

Enhanced accuracy of raw material dimensions is the first task in building a minimum cost production system. Management of members greatly affecting the welding process is important and was given priority as follows.

4.1.1 Low material grade and discontinuation of blanking process

The outer panels of the cab have a complex shape and are designed with a large drawing depth, which is susceptible to cracking and wrinkling in the press process. In addition, forming the panels is difficult. As a countermeasure, a blanking process is added and high-grade materials are used to expand the forming limits. In both cases, the number of processes is increased and material cost is increased, thereby increasing the panel cost.

To use lower grades of cab panel materials and to discontinue the blanking process, (1) Panel structure design taking productivity into consideration right from the cab concept stage and (2) Improvement in die making were undertaken. The results of these measures are described below.

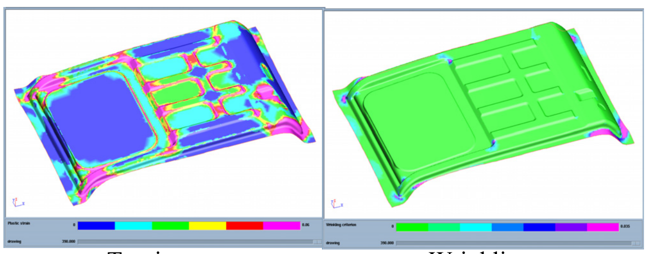
(1) Panel structure design taking productivity into consideration

To lower panel material grades and to discontinue the blanking process, the panel shapes must be made as simple as possible to make them easier to form. The design plan was studied by combining forming simulation analysis (**Fig. 5**) and trials with actual panels, in addition to the know-how gained in the past. The development concepts for these measures are described below (**Fig. 6**).

1) To set the drawing depth low after studying the panel structure.

2) To choose a radius shape that can be formed to prevent the cracking and wrinkling that occur when parts and components with a small radius are formed such as embossing.

3) To reduce forming that uses a cam die to a minimum by choosing shapes that can unify press directions into one.



Tension Wrinkling

Fig. 5 Examples of simulation analysis

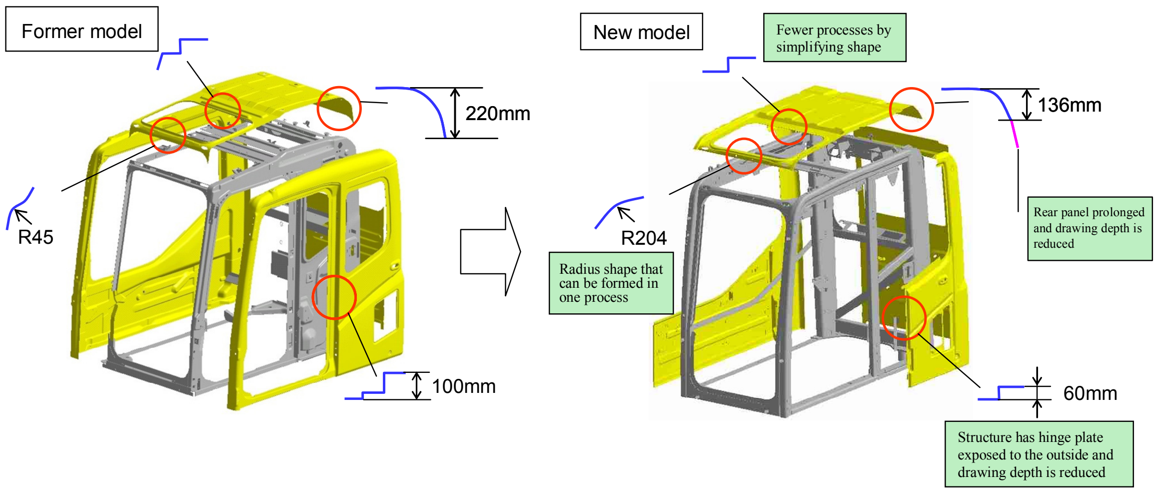


Fig. 6 Comparison of panel structures

(2) Improvement of die making plan

A study of the panel structure taking productivity into consideration as mentioned above is an important task, but remains as a change within design restrictions. It is similarly important to build a die making plan that promises good formability. In cooperation with a die manufacturer, optimum die shape was designed for the die making plan (**Fig. 7**).

The following concepts were developed for this process.

1) To add a slit blade in the drawing die. The material is made easy to flow by cutting it immediately before drawing.

2) To develop the optimum radius shape and a material that is easy to flow.

(Parts that are not related to a product)

3) To add a bead shape and to appropriately provide a tension.

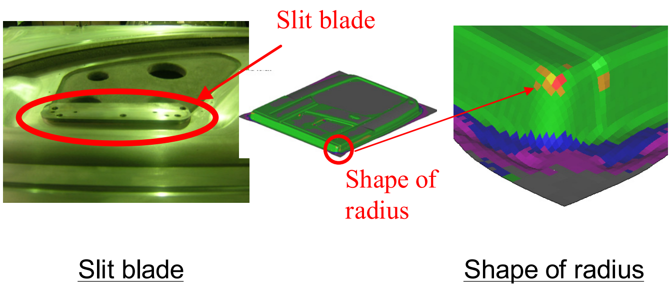
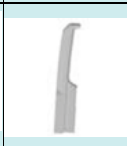


Fig. 7 Die making plan

(3) Research results

After implementing these measures, panel materials of a lower grade and discontinuation of the blanking process, which are the targets shown in **Table 2**, were accomplished, leading to a cost reduction of panel materials.

Table 2 Research results

Panel	Rear left panel	Rear right panel	Roof panel
Shape			
Target material	SPCC	SPCC	SPCC
Material used	SPCC	SPCC	SPCC
Blanking	None	None	None

4.1.2 High-accuracy bending technique of the A-pillar

The A-pillar of the cab is made of deformed steel pipe and has a complex shape. It is therefore not easy to bend steel pipe accurately. Many of the cab members are sandwiched by the A-pillar during temporary assembly and it was very important to improve the bending accuracy of the A-pillar. The bent shape of the A-pillar is illustrated in **Fig. 8**. The results achieved by the bending techniques for small-radius bends and large-radius bends are shown below.

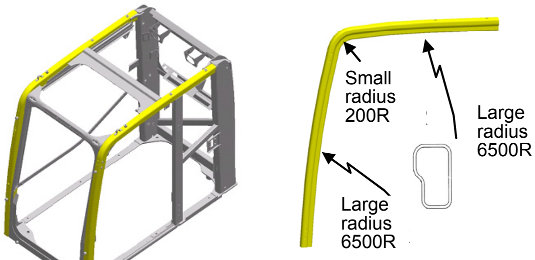


Fig. 8 Shape of A-pillar

(1) Development of small-radius bending technique

The rotary pulling and bending method, which was reputed to be the best in formability, was selected as a technique for small-radius bends (200R) (**Fig. 9**). When a deformed steel pipe is bent, in general, a bending curvature of R = 2.5D or larger is required for steel pipe diameter D, whereas the design value in this development task was R = 1.7D. Accurate forming therefore seemed difficult. After making a preliminary study by simulation (**Fig. 10**), trial and error was repeated under different machining conditions. The points used in forming pipes are as follows:

1) To eliminate the clearance between the die and pipe to prevent flattening of the pipe during forming.

2) To apply an appropriate axial compression force from the rear using a back booster during forming to prevent thinning of pipe wall thickness.

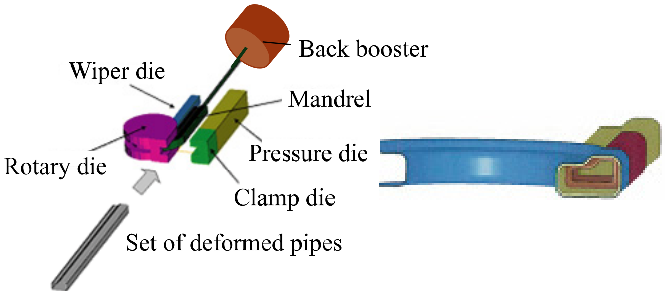


Fig. 9 Rotary pulling and bending mechanism

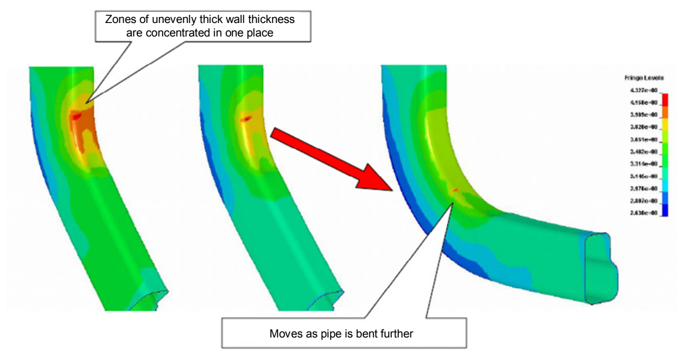


Fig. 10 Simulation analysis

Figure 11 summarizes the impacts of each machining condition on bend quality. By selecting appropriate machining conditions, pipes can be bent, but ranges of condition are small and conditions must be managed strictly.

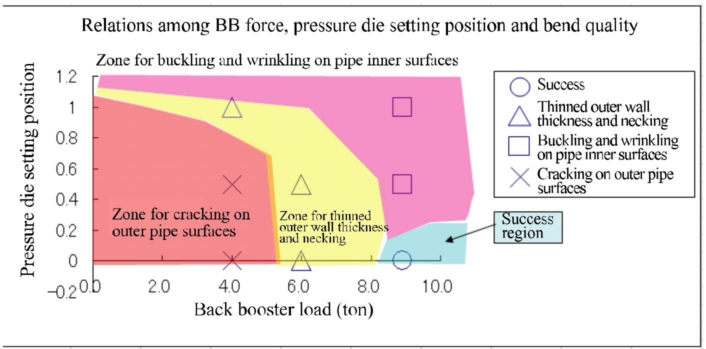


Fig. 11 Impacts of machining conditions on bend quality

(2) Development of large-radius bending technique

A stretch bend mechanism was selected as a technique for large-radius bends (6500R) (**Fig. 12**). This mechanism pushes the pipe to a die while pulling its ends toward the die so that two large radii can be formed at one time. Furthermore, it features removal of distortion made in previous processes. The points used in forming pipes are as follows.

1) To pull a pipe axially and bend correctly along the die.

2) The bending radius cannot be too small.

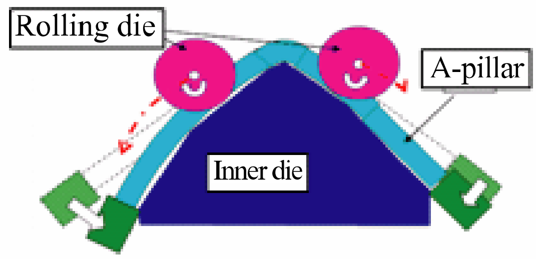


Fig. 12 Stretch bending process

(3) Result of research on high-accuracy bending technology of A-pillar

In the early development stage of this research, the flatness failed to reach the target of 2mm or less and another process for correction was needed. However, at the end, the target flatness was achieved (**Fig. 13**).

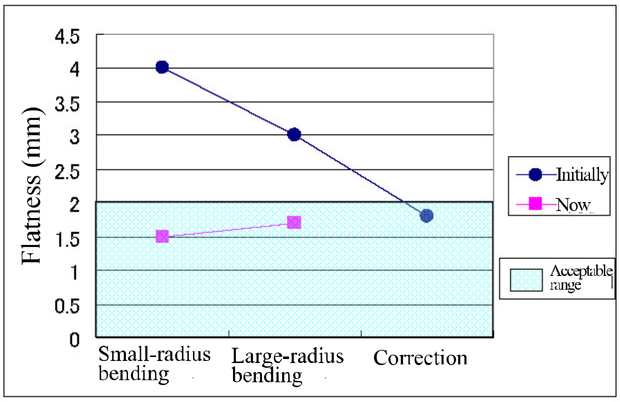


Fig. 13 Flatness of A-pillar

4.1.3 High-accuracy 3D cutting of pipe

When joining cab pipes, in the past, pipes were cut straight and the material to be filled inside their holes was placed by welding and pipes were then joined, resulting in waste in both the number of parts and man-hour (**Fig. 14**). Using a 3D pipe cutter that can cut pipes flexibly and a new design for a welded joint that is tied to the radius part of the pipe, clearance can be eliminated and pipes can be welded without any prior processing. This method eliminates a member for mounting, as well as welding and G finishing processes (**Fig. 15**).

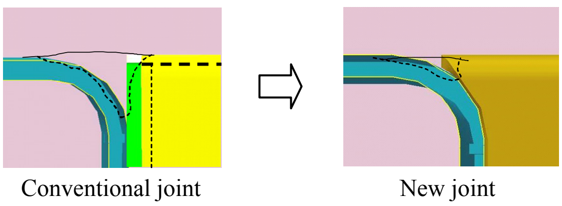


Fig. 14 Pipe joint

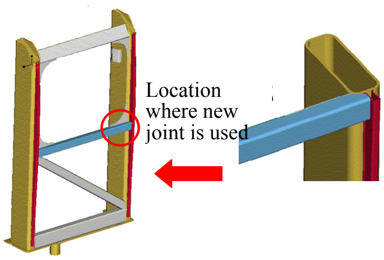


Fig. 15 Example of location of new joint

(1) Development of high-accuracy 3D pipe cutting

The accuracy requirement for cutting of pipe ends is high when a 3D cutting shape is used as a welding joint. Some panel members especially require cutting of deformed steel pipes in a complex 3D shape and this could not be achieved by a conventional cutter. A laser cutter with eleven NC axes that could cut steel pipes of a long length was used (**Fig. 16**). The cutter has a high-output laser-beam output device and has eleven axes for carrying in and out, as well as for moving, of steel pipes and for a torch. By feeding a pipe into the machine without cutting it as a prior process, a finished pipe can be machined. The points for forming at a high accuracy using this machine are as follows:

1) To manage accuracies for sectional shapes of steel pipes and amount of torsion within a certain range.

2) To correct shears and torsions in the sectional shape of a pipe during pipe cutting.

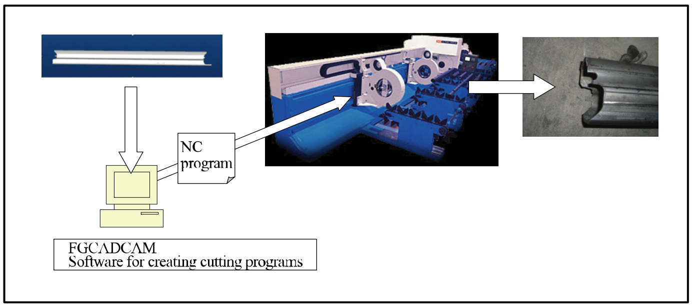


Fig. 16 3D pipe cutter

4.2 Welding process

As a characteristic of the new structure of cabs, the welding method has been changed from spot welding to arc welding and the weight of weld deposition has greatly increased. A search sensor and arc sensor are used in normal robot welding. However, panels are thin and the weld line is short, making it difficult to apply the search and shift function. Even if these sensors are used, their efficiency lowers significantly. To minimize any cost increase, 100% automation of robot welding and searchless welding were aimed for. This necessitated (1) High-accuracy temporary assembly system and (2) A robot system that allowed optimum welding position.

4.2.1 High-accuracy temporary assembly system

In searchless welding, works need to be assembled tentatively at a high accuracy. As mentioned above, technology for machine members at a high accuracy was developed and new ideas for temporary assembly jigs were also needed. For the structure of the temporary assembly jig, the conventional method of temporarily assembling works while forcibly distorting works by a constraint using a cylinder was revised. A method to temporarily assemble high-accuracy members without applying a forcible constraint and to constrain them as they were by a clamp was devised (**Fig. 17**).

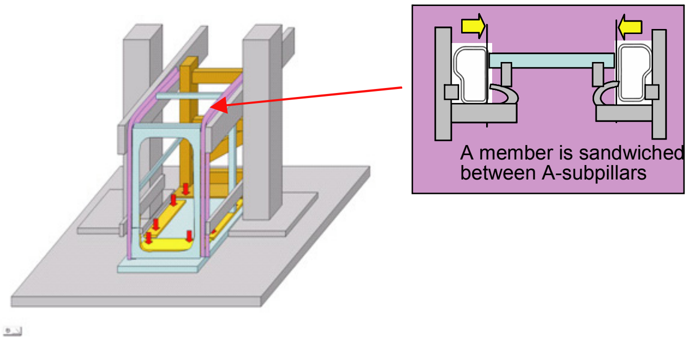


Fig. 17 High-accuracy temporary assembly system

Figure 18 shows the measurement results of clearances of works set on a welding robot and deviations from teaching values. After temporary assembling, both clearances and deviations from teaching values were 1mm or less, paving the way for searchless welding.

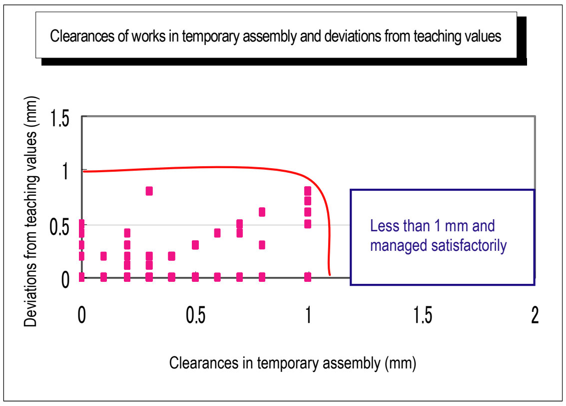


Fig. 18 Clearance and deviations from teaching values

4.2.2 Robot system

A welding system integrating both a positioner and robot allowing a good position relationship between the work and welding machine, and an optimum welding position was used for the welding robot. A long arm robot that houses cables was also used as the welding robot (**Fig. 19**). This allowed down hand welding in all positions, paving the way for robot welding of especially weld lines inside and in the bottom of a cab.

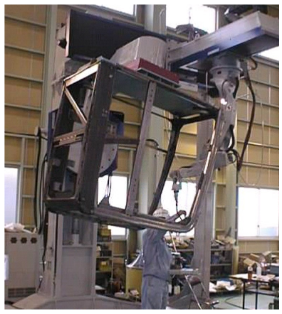


Fig. 19 Robot system

4.2.3 Structure of weld line

To accomplish 100% automation of welding, it is important that the cab structure allows automated welding as a precondition, even though the development of the foregoing robot system is important. This was incorporated as a concept from the design stage. Almost all members to be welded were made visible and the structure allowed lap welding and fillet welding. Care was exercised especially with the following points (**Figs. 20, 21**).

(1) Framework structure with which all weld lines are visible. Discontinuation of composite work processes and one process for the entire inspection process for welds.

(2) Building of a structure to eliminate interference parts of torch.

(3) Jig concept that avoids interference by building a one-chuck structure and discontinuation of welding of interfered members.

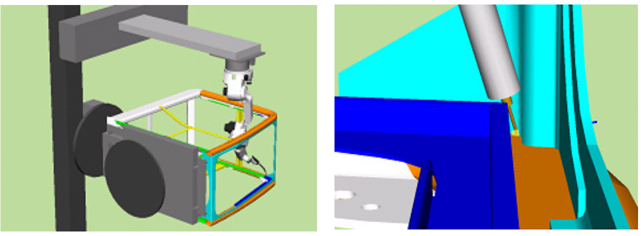


Fig. 20 Image of avoidance of interference

Fig. 21 Welding on floor side

4.3 Finishing process

The finishing work accounts for a large portion of man-hour among the entire processes for cab manufacture. Reduction in finishing work is important in building a minimum cost production system. The quickest solution to reduce finishing man-hour is to reduce wasteful finishing. To achieve this, an activity to discontinue excessive finish was undertaken in cooperation with the design and quality assurance departments. For example, the standard for quality of flare welded parts in the front part of the cab that required much finishing work was changed to a higher rank for portions above eye level and to a lower rank for portions below eye level. Approval of the related departments was obtained for weld zones of the higher rank by continuous welding and of the lower rank, by intermittent welding. Finishing was eliminated for both ranks.

5. Accomplishment Status of Technology

After implementing the foregoing measures, initial targets had generally been accomplished (**Table 3**). Searchless welding was not accomplished because dispersions in the amount of distortion in framework welding were 1mm or more and searching was necessary in welding cosmetic panels. This task should be addressed in the future.

Table 3 Status of technology accomplishment

Process	Member	Objective	Target	Degree of accomplishment	
Member	Panel	Lower grade of material	Material SPCC	SPCC	○: Accomplished
		Discontinue blanking process	Discontinued	Discontinued	○
	Pipe	High-accuracy bending	Flatness 2mm or better	2mm or less	○
		High-accuracy 3D cutting	Clearance 1mm or less	1mm or less	○
Welding	Framework	High-accuracy temporary assembly	Clearance 1mm or less	1mm or less	○
		100% automated welding	100% automated	100%	○
		Searchless welding	100% searchless welding	95%	△: Not accomplished
Finish	Framework	Discontinue excessive finish	Discontinued	Discontinued	○

6. Subsequent Activities

As outlined above, the safety of the cab in rolling over was secured and a minimum cost production system was built. However, as mentioned above, the cab weight increased about twice compared with before because the wall thickness of structural members of the pillars was increased and pillar supports were reinforced by the addition of a reinforcing rib and other members. The square steel pipes used in the C-pillar in the rear are the most important members for ensuring the strength and their purchasing cost increases the higher their wall thickness is. A rational reinforcing method was therefore studied focusing on the C-pillar.

6.1 Approach to reinforcing method

Buckling of the C-pillar first absorbs crash energy as a deformation mode in a ROPS test (**Fig. 22**). Curbing of this buckling may achieve a structure that allows energy absorption by the entire cab compared with the conventional structure. **Figure 23** illustrates the ideal deformation mode.

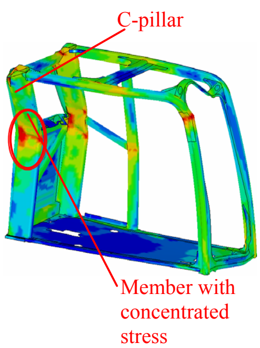


Fig. 22 ROPS analysis

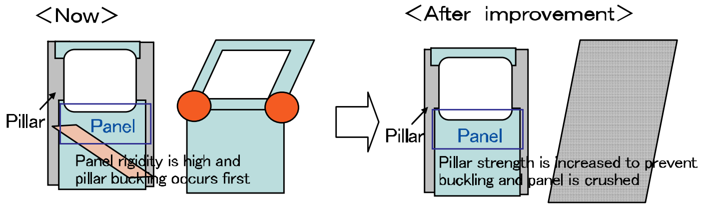


Fig. 23 Deformation mode in ROPS test

6.2 Partial reinforcing method

(1) Study of structure

Insertion of a rib was selected as a partial reinforcing method due to its high productivity and to a wide strength variation. The process for this reinforcement is shown in **Fig. 24**. The new structure reduces the wall thickness of C-pillar about 30% (**Fig. 25**).

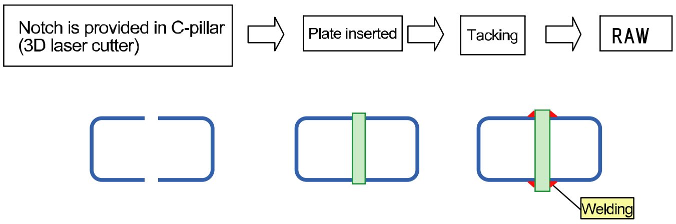


Fig. 24 Manufacturing process for rib insertion

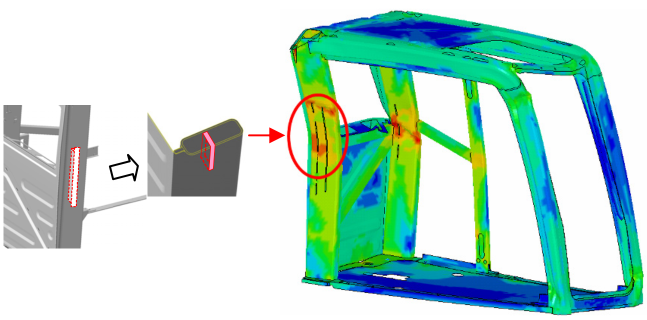


Fig. 25 Rationalized ROPS cab manufacture

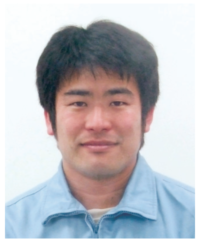
(2) Result of ROPS test

Target absorption energy values in sidewise pushing, rearward pushing and upward pushing were accomplished within a displaceable range regarding the foregoing rationalization plan.

7. Conclusion

A cab meeting the roll-over protection safety standard was developed for the protection of operators of hydraulic excavators. A minimum cost production system for the cab was built. At present, this technology is used with cabs for construction machinery other than hydraulic excavators and the cab manufacturing processes are being unified. Future plans include enhancing the value of this research by applying the technology to components other than cabs in addition to pursuit of a further improved cab structure and manufacturing method.

Introduction of the writer



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[A few words from the writer]

Recently, regulations have become stricter and needs for safety and the environment are increasing with a focus on automobiles. In response to these trends, enterprises must make efforts to not only meet the regulations, but also to minimize cost increases. The innovation of manufacturing encompassing simultaneous actions from the design stage to all subsequent processes (from material processing to the finish process) to meet quality requirements will greatly impact the future development efforts at Komatsu. The Manufacturing Engineering Development Center, Production Division, will also contribute toward improving SVC of entire welded structures by similar methods.