Technical Paper

Optimization of Casting Shapes

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A system to create optimum shapes of casting components has been established using a shape optimization technique, and is reported as reducing costs, while improving strength and casting productivity.

Key Words: *Casting, Cast Steel, CAE, Shape Optimization, Solidification Analysis*

1. Introduction

Today, computer aided engineering (CAE) is used in many segments of business from design to production engineering and CAE has become an indispensable tool for product development. Parallel with the sophistication of CAE, CAE is now used in prototyping and testing also, making a contribution in shortening the development lead time and in enhancing product performance. Higher efficiency in product development has been demanded such as "Product design high in product competitiveness that is less affected by large fluctuations in material and energy costs" and "Product design that assures a longer durability."

To this end, the use of CAE in product development has become an everyday tool of product development. At the same time, the load on products with a high degree of design freedom is increasing. Komatsu's construction machinery is characterized by high utilization of castings and these castings are used in structures that are especially important. Castings offer a relatively high degree of freedom of shape and shapes that are stronger than structures manufactured by sheet metal working and welding because castings are manufactured by pouring molten metal into a mold as their manufacturing method. In design, however, load conditions to endure a variety of operating conditions are set and the strength has to be satisfied under all conditions. Additionally, in conventional product design studies, it is difficult to design shapes that maximize the characteristics of castings due to problems associated with limited development lead time, failing to fully utilize the feature of castings, and the high degree of freedom of shape that castings offer.

Therefore, a new tool for studies of structure that provides a longer durability in the design and for shapes that utilize the degree of freedom of shape is required. A reduction in development load cannot be achieved unless CAE is a tool of the proposal type, instead of an evaluation tool. The use of shape optimization to automatically calculate efficient shapes by a finite element mesh was therefore evaluated. On the other hand, many cast parts used as strength members are made of cast steel that features both strength and toughness. Compared with cast iron, however, cast steel has many constraints in its casting plan. An improvement technique in structural and production aspects that satisfies both "efficient shape in design" and "quality assurance in casting productivity" is described in this paper.

2. Shape Optimization

2.1 Types of Shape Optimization

From early on, the optimization technique has been used in various fields. Thanks to the recent advances in the performance of personal computers, a technique to automatically calculate optimum shapes in FEM analysis is used. Generally, optimization techniques after a basic structure is decided are grouped into parametric optimization that uses the dimensions of various members as basic variables and into non-parametric optimization that uses surface shapes as design variables (**Fig. 1**). In parametric optimization, outside dimensions, plate thicknesses and other design variables must be defined in advance from a condition that is approximates the final shape, making it difficult to fully utilize the degree of freedom of casting shapes. The use of non-parametric shape optimization was studied aiming at utilizing the characteristics of castings. This allows automatic search of efficient shapes of members, which was time-consuming in the process of repeating CAD creation and FEM analysis in the conventional development process, by FEM analysis, thus reducing the time required for trial and error.

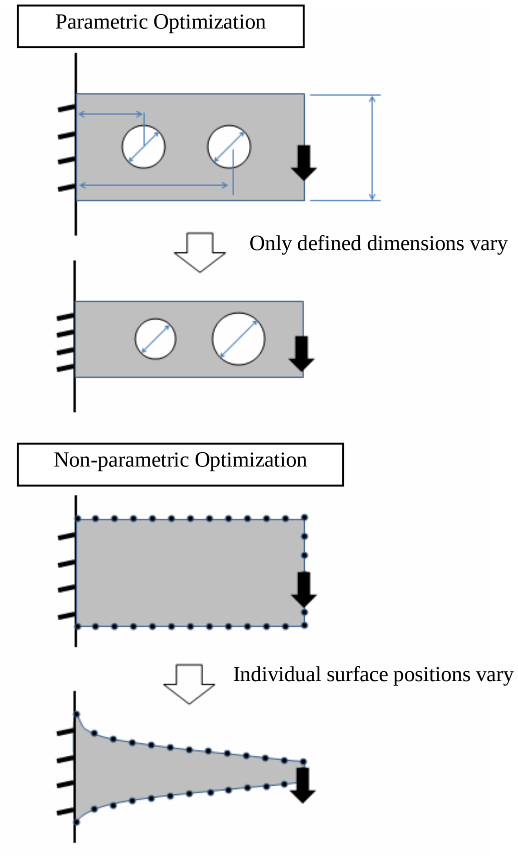

Fig 1 Types of shape optimization

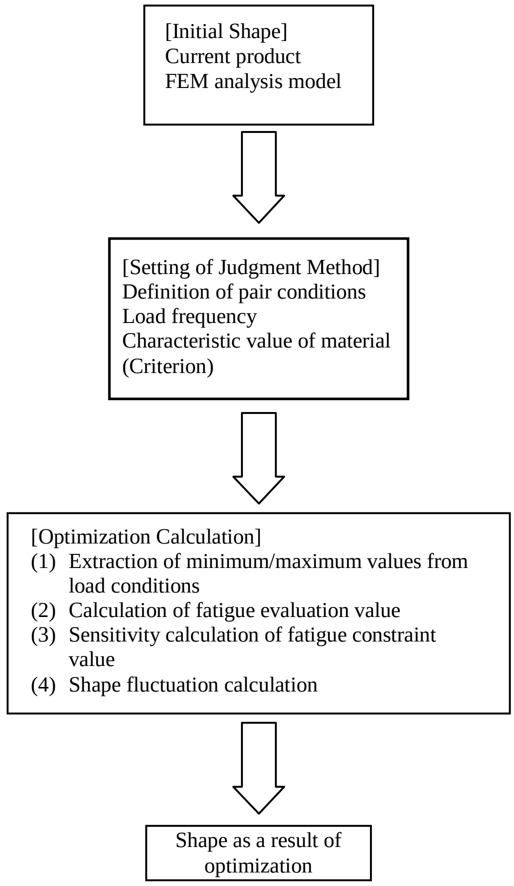

Fig.2 Optimization by fatigue durability evaluation

2.2 Use of Shape Optimization

In shape optimization, shapes are decided so that evaluation values obtained by combining specified physical quantities such as objective functions and constraint conditions become minimal. Physical quantities considered in objective functions and constraint conditions include weight, judgment stress and natural frequency. Optimization (minimization) of an objective function value under constraint conditions is performed by sequentially varying a surface shape as a design variable. These objective functions and constraint conditions must be combined to satisfy a design objective. In changes that aim at reducing material cost, indicators are generally used such as weight as an objective function and judgment stress as a constraint condition. In general, it is possible to maintain stresses individually under plural conditions. In this paper, a fatigue evaluation criterion is calculated from plural load conditions and this criterion is used in constraint conditions. This allows direct evaluation using an indicator of durability used as a criterion and judgment can be made easily compared with individual evaluations (**Fig. 2**).

2.3 Example of Optimization Calculation

The flow of calculations used in shape optimization is described in the following. **Figure 3** illustrates the flow of a structural design including optimization calculation. The flow incorporates an optimization study shown by a red frame in a conventional design study. Using a shape plan calculated in optimization, the final product shape is built in.

Figure 4 shows an undercarriage component of a construction machinery actually optimized by this flow. A weight reduction was used as a targeted optimization objective function and the indicator of a fatigue durability evaluation explained in Section 2.2 was used as a constraint condition. A fatigue durability higher than that of current products was included among the conditions. As limits on shape variations, conditions that also incorporated variation limits of manufacturing conditions against a molding direction and against a minimum wall thickness of castings were used as manufacturing conditions in addition to clearances between components.

A result of shape optimization is shown in **Fig. 5**. The illustrations in (a) and (d) show CAD shapes and illustrations in (b) and (c), FEM shapes after optimization calculation.

Principal differences are a variation in the shape of holes to mitigate stress on hole rims and thinning of wall thicknesses of base portions that contribute to a reduction in stiffness. Using the shape obtained in (c) as a reference, CAD in (d) was created and this model reduced the weight by about 5%.

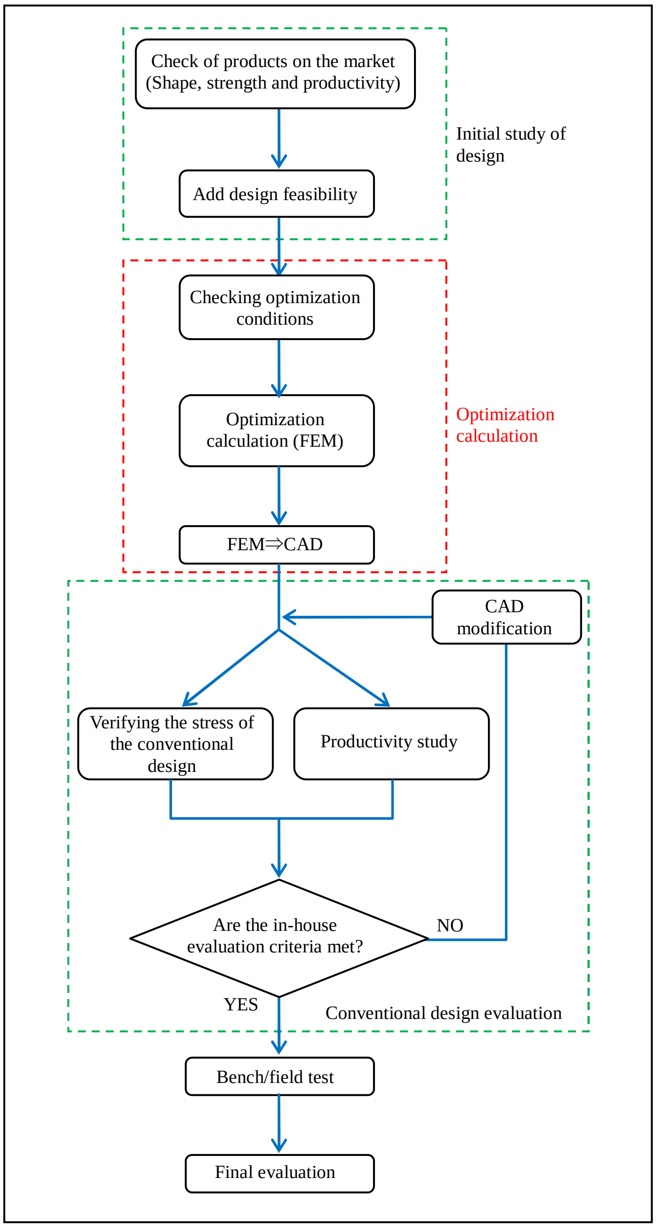

Fig. 3 Flow of the casting shape optimization

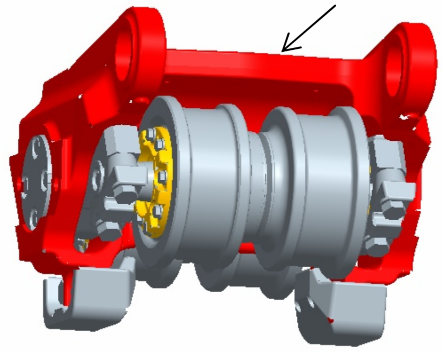

Fig. 4 Component studied for optimization

2.4 Evaluation of Productivity

Cast parts made of cast steel are manufactured by pouring molten metal into a mold. The amount of solidification shrinkage of molten metal is large with cast steel and hollows called "shrinkage cavities" are produced inside products unless the casting plan design is appropriate. These flaws cause strength deficiency and are not allowed. These shrinkage cavities are controlled by adding an extra shape called a casting riser to the product when molten metal is supplied to a product. The costs to melt, cut, maintain and repair this casting riser are also added to the product cost. It will be necessary to verify whether a cost reduction can be achieved for the entire cost including the production cost, parallel with material cost reduction by controlling flaws and reducing product weight. Solidification analysis was conducted for this verification using casting CAE of components whose shape was changed as shown in **Fig. 6**. Flaws of conventional components are checked by inspection and the shrinkage cavity indicator of optimized components is improved compared with conventional components. The casting plan for the casting riser is also similar to the one currently used and has been verified as problem-free. The change in shape has produced higher quality and equivalent cost.

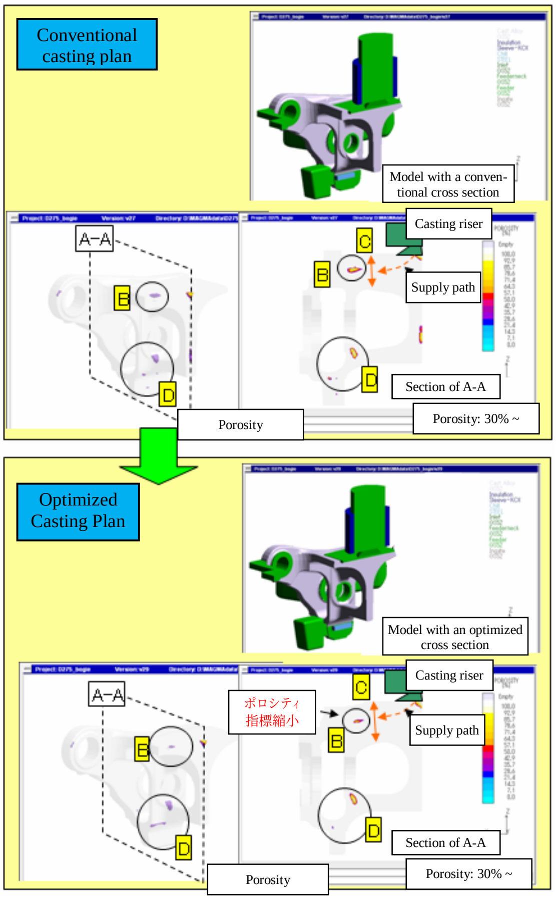

Fig. 6 Result of solidification analysis

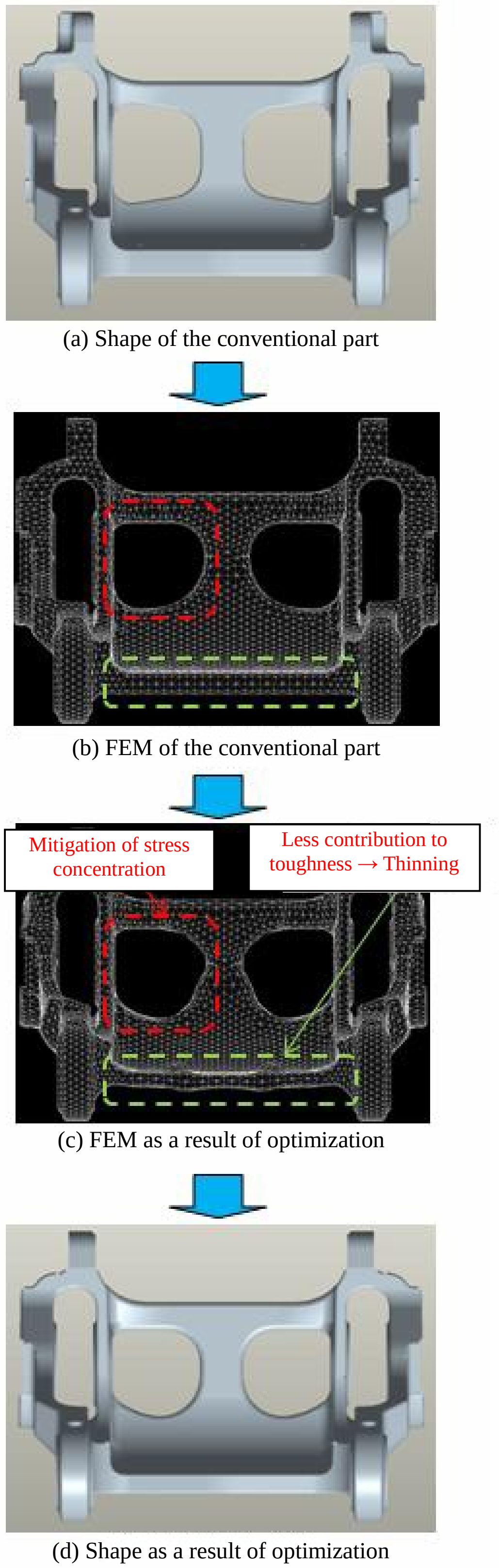

Fig. 5 Result of shape optimization

3. Evaluation of Trial Manufacture

The studies described above have shown that a structural improvement can be made with presently-manufactured components as plotted in **Fig. 7**. The productivities of the conventional and new components are equal. The new components were installed in equipment and were evaluated. In **Fig. 7**, the results of bench stress tests shown on the right compared with current components shown on the left indicate that stresses generated in the new components are not as large as those on current components. The new components were installed on machines for testing and were proven to meet the durability target. These results show that shape studies by optimization are effective.

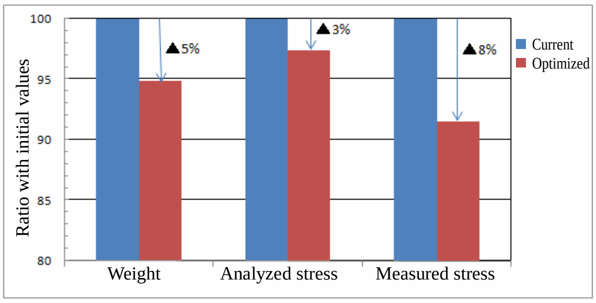

Fig. 7 Result of equipment evaluation

4. Conclusion

The following was found in the studies of structure and production of castings by shape optimization through analysis and equipment evaluation:

(1) Studies of shapes by shape optimization are effective as shape plans under initial design plans that are closely examined to some extent.

(2) Both design judgment and structural knowledge to evaluate validation are important to return optimization results from FEM to CAD.

(3) Some shape changes are not problematic in terms of casting productivity. However, problems may occur with castings with thin walls and the prior conditions must be studied before optimization.

Introduction of the writers

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[A few words from the writers]

Quality management of cast parts is of critical importance. Efforts will be made to develop technology that can create robust and optimum shapes that excel in structure and production.