Process Design for the Hot Forging of Asymmetric Rail to Symmetric Rail

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The process design of hot forging, asymmetric to symmetric rib-web shaped steel, which is used for the turnout of express rails has been studied. Owing to the great difference in shape between the initial billet and the final forged product, it is impossible to hot forge the rail in a single stage operation. The numerical simulation for hot forging of asymmetric shape to symmetric shape was carried out by using commercial FEM code, DEFORMTM-2D. For comparison with the simulation results, a experiment of flow analysis using plasticine was also carried out. The results of the flow experiment showed good agreement with those of the simulation.

Key Words : Asymmetric, High Speed Rail, Hot Forging, Symmetric, Process Design

1. Introduction

The process design for hot forging has been greatly dependent upon the empirical experience of engineers because there are numerous process variables on the basis of constant volume such as prediction of metal flow, yielding condition, heat transfer between dies and forging material and friction behavior, etc.

Recently, most of the work has concentrated on plane symmetric or axi-symmetric products (Choi, 1995 ; Qingbin, 1997 ; Ward, 1998 ; Guo, 1999 ; Doege, 2000 ; Fujikawa, 2000 ; Rodrigues, 2002). Ward (1998) analyzed the effects of heat on material and dies during multi-stage hot forging of train wheels through the commercial finite element code DEFORM. Qingbin (1997) studied the effect of die temperature and forging speed by the simulation of thermal behavior during high speed hot forging of AISI 1045 discs. Doege (2000) studied closed dies to produce spur gear, helical gear and connecting rod. Choi (1995) developed an automatic system that is available to design a blocker to forge rib-web shape products. However, there has been great interest in forging asymmetric or axi-asymmetric products, but very few reports have been found on this subject. Generally, rib-web shaped asymmetric KS70S rails for an express train are produced in a specified fixed shape, but the shape are transformed to symmetric KS60KG at the rail turnouts. In the present study, the process design of forging the asymmetric rail to the symmetric rail at the turnouts is carried out by the rigid plastic finite

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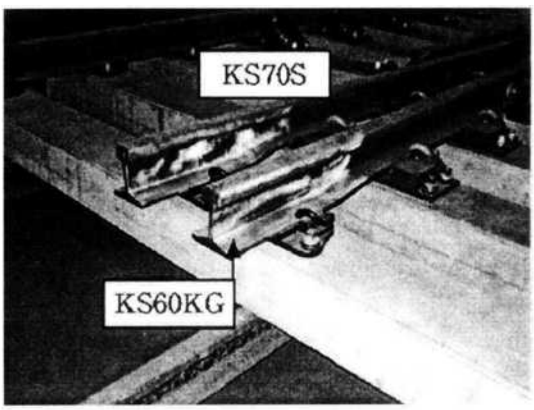
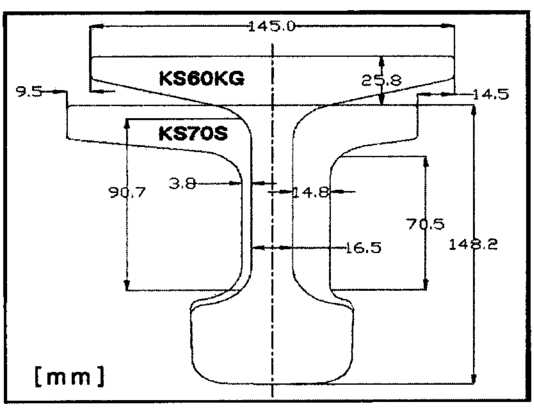
element code DEFORM™-2D simulation. The process design through computer simulation is also compared with an experimental inspection of the flow behavior with plasticine simulation material.

2. FEM Analysis

A high speed rail has a transition range at the turnouts. Owing to the difference in height and shape between the rib-web asymmetric KS70S and the symmetric KS60KG as shown in Fig. 1, it is impossible to forge in a single-stage operation. Therefore, a process design for multi-stage forging is needed. The dies and inserts for multi-stage forging process is shown schematically in Fig. 2. The dimension of left and right dies are adjusted to forge the rail to eccentric shape. The DEFORM™-2D is used for the FEM analysis.



(a) Photograph of turnouts



(b) Schematic comparisons of the two rail shapes

Fig. 1 The shape of transformed parts from KS70S to KS60KG in turnouts

2.1 Finite element modeling

The simulation mode is plane strain and non-isothermal, that means the heat transfer between rail and dies is considered.

The rail material is rigid-plastic and the flow stress of the AISI 1055 steel is used. The dies and inserts are made of AISI H-13 and assumed as rigid bodies over forging process. The left die is fixed and the right and the upper die speed is 2 mm/s. The boundary conditions are an initial rail temperature of 1050℃, a preheated die temperature of 100-200℃, considering heat transfer of all the surface and the internal body of dies and inserts, friction factor 0.1 between the dies and friction factor 0.3 between rail and dies. The thermal properties of the materials are listed in Table 1.

2.2 Results of FEM analysis

Figure 3 displays the initiation of folding during subsequent forging processes when there is a fillet angle of 45° between the side dies and the insert. Designing with an increased fillet angle of 60° can prevent the folding phenomenon and reduce friction wear due to stress concentration between the die and the insert.

Table 1 Thermal properties of materials

Material	Thermal conductivity (W/m·K)	Heat capacity (J/g·K)
AISI 1055	51.9	0.472
AISI H-13	28.6	0.460

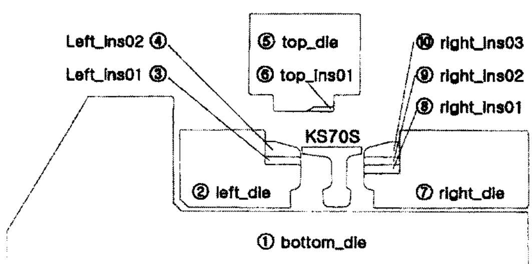


Fig. 2 Schematic illustration of forging dies

Figure 4 shows the simulated results when the machining allowance is 0.6 mm for the whole part. The simulated final shape was within the machining allowance of 0.6 mm, as shown in Fig. 4(b). However, the load increased rapidly at the end of the first forging stage, as shown in Fig. 5. The rapid increase in the load is attributed to the increase in the contacting area

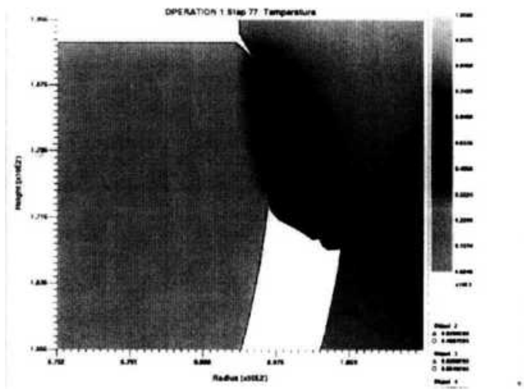


Fig. 3 Folding initiation at a small fillet angle (45°) of moving die and insert

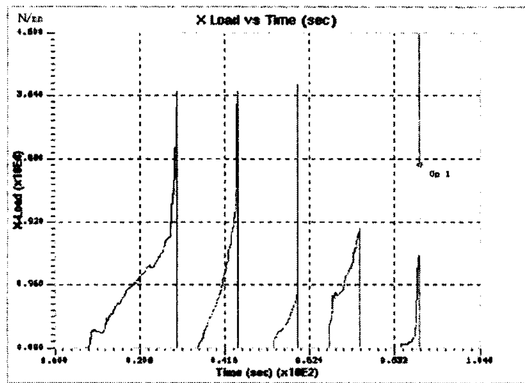
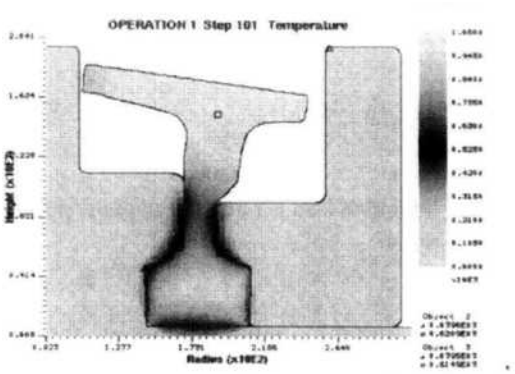
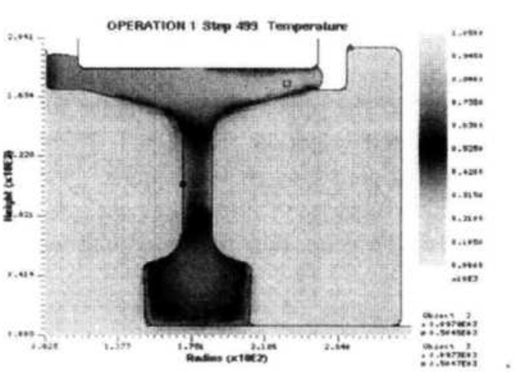


Fig. 5 Impressed load per unit length of the side die

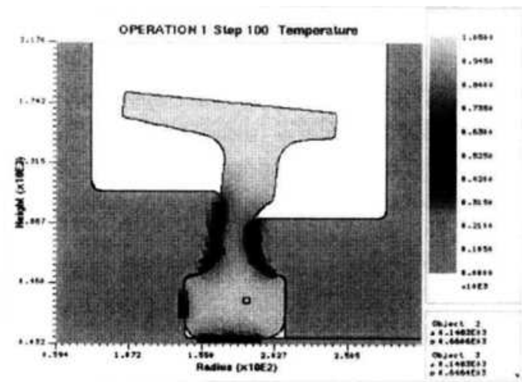


(a) The end of 1st stage

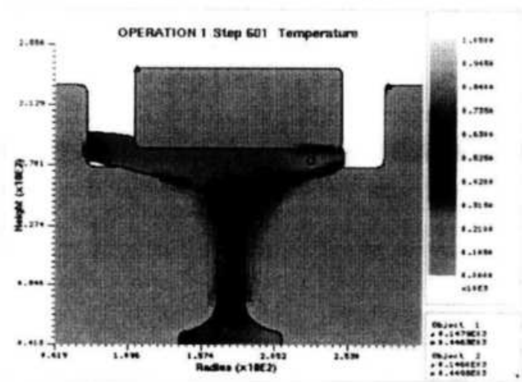


(b) The end of 5st stage

Fig. 4 Simulated forging process (die velocity 2.0 mm/s, preheating 100℃)



(a) The end of 1st stage



(b) The end of 5st stage

Fig. 6 Simulated results of modified process of Fig. 4

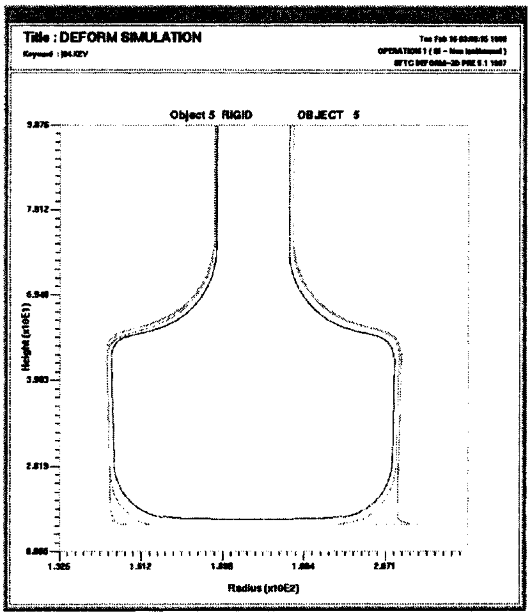
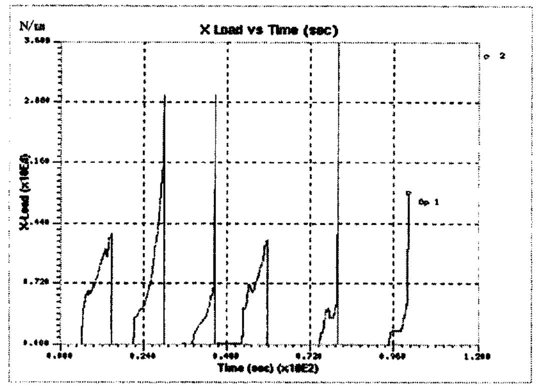
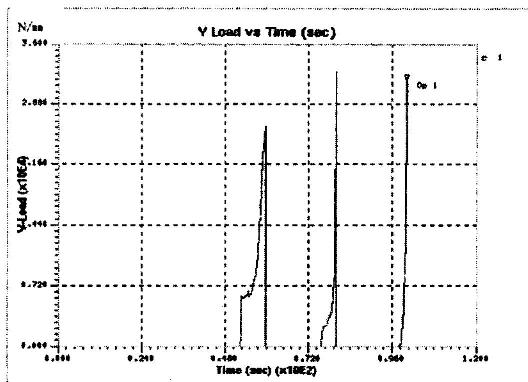


Fig. 7 Comparisons of the final forged product and the desired shape



(a) Side die



(b) Top die

Fig. 8 Impressed load per unit length of the side and top die

caused by filling of the internal die cavity with the finished forming of the head of the rail at this stage. Therefore, optimal die design is necessary in order to avoid an increase in the forming load.

Figure 6 shows the modified forging process of Fig. 4 to prevent load increase during forming. The machining allowances are 1.0 mm for the head of the rail and 0.6 mm for the other surfaces. A high amount of machining allowance at the head of the rail reduces the amount of metal flow through the web to a relatively short rib, but the high amount of metal flow in the 3 stage process makes it possible to form the full shape of the rib.

Figure 7 compares the final and the forged shape of the rail. The final forged shape has a sufficient machining allowance. Fig. 8 shows that the maximum forging load per unit length impressed to the right die at each stage was about 30 kN/mm. As shown in the figure, the first stage (Fig. 4(a) and Fig. 6(a)), which forms the rail head, does not have the rapid increase in load that appeared in the process of Fig. 4. However, the load increase of the second and third stages shows an increase similar to that of the first stage. Though the amount of deformation in the subsequent stages decreased, the load increased rapidly because of the increased contacting area between the material and the dies, and the cooling of the material. The load per unit length impressed to the upper die was similar to that impressed to the right die (Fig. 8(b)). Therefore, the required press load is 30 kN/mm$\times$720 mm$=$21,600 kN. If we put 2,940 kN as the load tolerance of the press, then the press load will be 24,540 kN.

3. Experiment

3.1 Testing facility and conditions

On the basis of the simulation results 70% by size of the actual dies and the inserts were made of Al5052. Fig. 9 shows the dies and the facilities set up on the press.

The rail shape specimens were made with plasticine simulation material stacked to the flow direction with 3 mm thick black and white plates

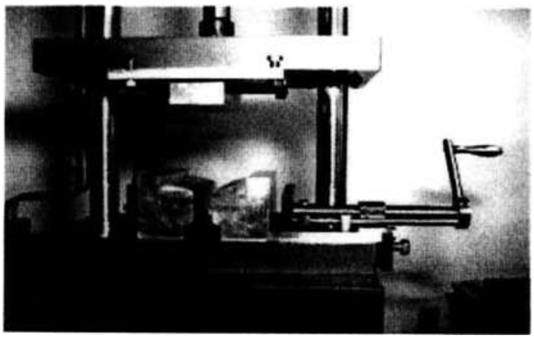
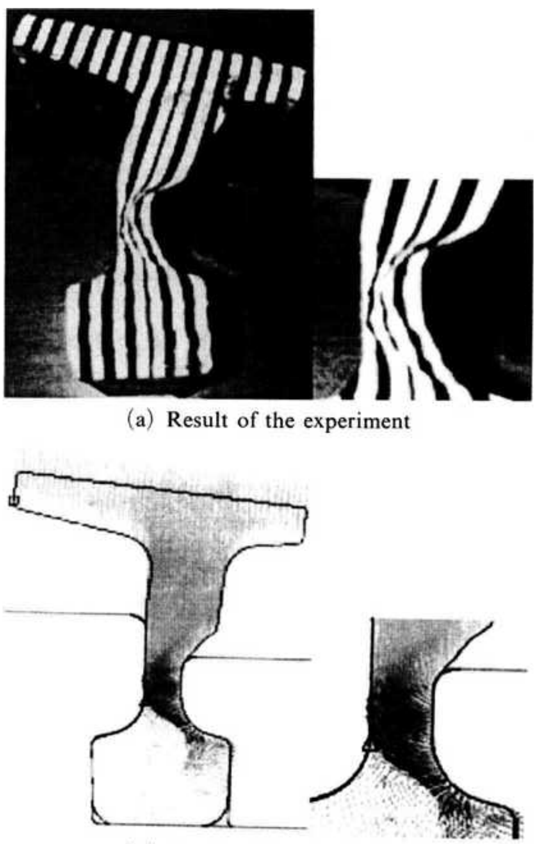


Fig. 9 Experimental set up



(a) Result of the experiment

(b) Result of the simulation

Fig. 10 Comparisons of the experimental result and the FEM simulation after the first process

as shown in Fig. 10(a).

The lubricant between the specimen and the dies was soapy water. The actual process condition was obtained with a plain strain condition by closing the opposite side of the dies to prevent material flow.

3.2 Experimental results

The experiment was carried out on the basis of the simulation. Fig. 10(a) shows the flow of plasticine when the first stage finished. The experimental results correspond to the DEFORM™-2D simulation of the material flow shown in Fig. 10(b).

Figure 11 displays the final forged shape of the two specimens. As the process proceeds, material flows to the fixed dies, and simultaneously to the rib then nearly perpendicularly and finally to the long rib. During forming with an upper die, the long rib shows a reduction in thickness because material flow occurs to the short rib side. The result corresponds to the simulation result for material flow.

The process design in the present study was applied to actual production. Fig. 12 shows the final stage of forging operation from asymmetric to symmetric rib-web shaped rail steel. Fig. 13 shows the comparisons of the cross-sections of before and after forging operations. The forged shape of the rail is within the machining allowance. Therefore, the process design in the present study seems to be applicable to actual production.

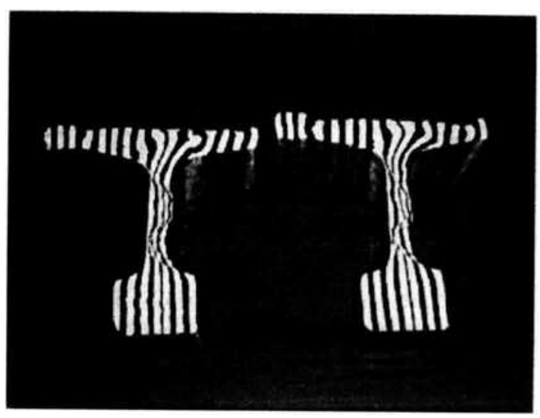


Fig. 11 Experimental result after final stage

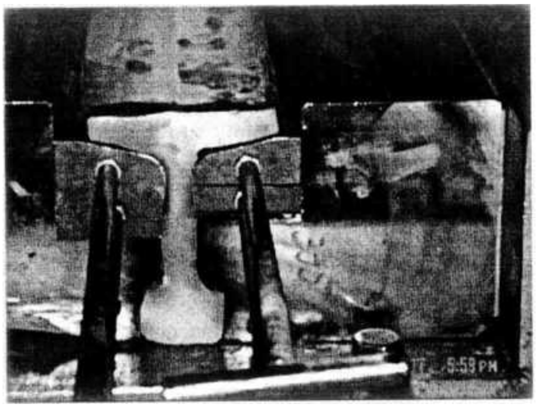


Fig. 12 The final stage of forging operation

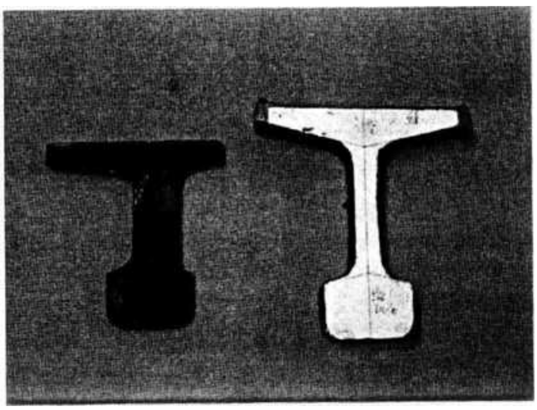


Fig. 13 The comparisons of the cross-sections of before and after forging operations

4. Conclusions

In the present research, finite element analysis and experiment were performed to develop multi-stage forging process for express rail which are transformed it's shape from asymmetric to symmetric at the turnouts. The finite element analysis using DEFORM^{TM}-2D enabled a great insight into the deformation of the rail during the entire process which gave informations of folding problems and forging load. The conclusions of this research are summarized as follows :

(1) In order to prevent folding defects between rib and web, it is needed to increase fillet angle over 60 deg. of the insert.

(2) Folding behavior and friction due to stress concentration reduced with increased fillet angle between the dies and the insert. In order to prevent folding at the cross point between the rib and the web, the beginning point of the taper to cause metal flow has to be close to the short rib.

(3) In order to reduce capacity of the press, different machining allowance has to be given for each rib and web surface.

(4) The experimental results of flow analysis using plasticine are in good agreement with the simulated result in terms of estimating metal flow.

(5) The forged shape of the rail using the developed process design by FE analysis is within the machining allowance. Therefore, It is possible to apply the developed process design to actual production.

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