Simulation Analysis and Research on Integrated Forming Process of Steam Pipe Nozzle

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Abstract. The FORGE® numerical simulation was used to analysis and research on the integrated forming nozzle process of the main steam pipe, and then guide sampling test plan and forming process evaluation. The results show that the maximum axial tensile stress appears in the middle of the forming process, which is on the inner surface of the extrusion deformation transition region, and the maximum radial tensile stress and equivalent strain appears at the end of the extrusion nozzle forming process, which is located in the inner surface area of the nozzle mouth, and it is easy to crack. For the weak position, it is necessary to increase the number of samples and test items to verify the overall quality of nozzle.

1. Introduction

The main steam super pipe line (hereinafter referred to as steam super pipe) is the main steam super pipeline or similar structure of the pipeline components in the construction of nuclear power plant at present[1-3]. The steam super pipe is a section of saturated steam pipe from the main steam pipe of the reactor containment mechanical penetration, to the first welding line of the lower limit of the main steam pipeline. Main steam super pipe requires high thermal parameters, the strong impact force under the accident condition, the higher safety requirements, especially for the nozzle zone which connects to the main steam safety valve[4-7]. Due to manufacturing technology capacity constraints, the previous main steam super pipe are made group welding between main pipe and nozzle, not only the process is simple, but the components increase many weld lines, reducing the overall security, at the same time increase in the workload of in-service inspection. With the improvement of manufacturing process, main steam super pipe nozzle begin to use the integral extrusion forming process which can effectively avoid the disadvantages of combination welding, however because the shape and dimension precision of the nozzle with high requirements, so the forming process of the nozzle has greater difficulty. This paper simulate and analyze the forming process of the main steam super pipe nozzle using Forge simulation software, and compared with the actual results, find out the metal damage law of nozzle forming process, estimate its internal quality, provide a reference for design, manufacturing and procurement of nuclear power components.

2. Technology Process of Forming Nozzle

The technology process of extrusion nozzle (Fig.1) forming is as follows: main pipe laying-out→locate prefabricated hole→Local heating of forming parts →extrusion forming nozzle→dimension check→heat treatment→sampling→mechanical property→blasting and dressing→nondestructive examination (NDE)→machining end plane→hydrostatic testing→finishing machining→final dimension check→marking→report review.
It is need to determine the location of the prefabricated hole before forming nozzle, and machining prefabricated hole according to the design method. Then heating the main pipe in the forming area by using local heating device, when heated to the specified temperature, the upperdie/lowerdie is arranged alignment to the prefabricated hole rapidly. Next the end plane of the upperdie is pressed downwards by the water/oil press, and the nozzle is formed by the upward movement of the lowerdie.

3. Build the Model and Setup Parameter

3.1. Design the Model
The model of the integrated extrusion forming nozzle with the mainstream technology is established, and the 3D model of the billet and upperdie/lowerdie are created at the same time, as shown in Fig.2.

Table 1. Chemical compositions (% mass fraction)

| Element     | C_{\text{max}} | Mn   | P_{\text{max}} | S_{\text{max}} | Si    | Ni_{\text{max}} | Cr_{\text{max}} | Mo_{\text{max}} |
|-------------|----------------|------|----------------|----------------|-------|-----------------|-----------------|-----------------|
| Content%    | 0.22           | 0.80-1.60 | 0.025          | 0.020          | 0.10-0.40 | 0.50            | 0.25            | 0.10            |

Table 2. Boundary parameter setting

| Billet initial temperature/°C | Upperdie/lowerdie initial temperature/°C | Upperdie press/T | Upperdie depress rate/(mm·s^{-1}) | Upperdie initial height/mm | Upperdie final height/mm |
|-------------------------------|------------------------------------------|------------------|----------------------------------|---------------------------|------------------------|
| 1230                          | 220(preheating)                          | 6000             | 15                               | 210                       | 0                      |
4. Results and Analysis

4.1. Deformation Temperature Analysis
Fig. 3 is the temperature profile of the nozzle forming process. As can be seen, although the upper die and lower die preheating 220°C, but because of the heat transfer, the billet temperature which contact mold area drops fastest. The core temperature of the billet has been at a high temperature, and low temperature zone exists in the contact area between the billet and the mold. During the forming process, the temperature of each region of the billet is above 785°C, and is in the range of reasonable hot forming temperature of the hot extrusion nozzle.

![Temperature distribution](image)

Fig. 3. Temperature distribution (Unit: °C)

4.2. Stress Analysis
Fig. 4 shows the axial stress distribution during the nozzle formation of the steam pipe. The billet is thermally formed after initial heating, so that the stress of the billet before the start deformation is zero, as shown in Fig. 4 (a). With the downward pressure of the upper die, and produce the axial tensile stress, continue to under upper die pressure, wall thickness increased, the billet axial tensile stress increases gradually, the axial stress extreme value appears in the upper die stroke 100mm, with the maximum of 38.3MPa, as shown in Fig. 4 (b).

![Billet axial stress distribution](image)

Fig. 4. Billet axial stress distribution (Unit: MPa)

Fig. 5 shows the radial stress distribution during the nozzle formation of the steam pipe. With the downward pressure of the upper die, and produce the radial tensile stress, as shown in Fig. 5 (a). Continue to under upper die pressure, the billet radial tensile stress increases gradually, the radial stress extreme value appears in the upper die stroke 205mm, with the maximum of 99.7MPa, which occurs near the inner surface zone at the end of the nozzle formation, as shown in Fig. 5 (b).

![Billet radial stress distribution](image)

Fig. 5. Billet radial stress distribution (Unit: MPa)
4.3. Equivalent Strain Analysis
Fig. 6 shows the distribution of the equivalent strain during the nozzle formation of the steam pipe. As can be seen, with the downward pressure of the upper die, the equivalent strain is larger between the billet and the mold. The maximum equivalent strain occurs in the contact zone of the billet/upper die, as shown in Fig. 6 (a). The upper die continues under pressure, the nozzle is gradually forming, the thinning of wall thickness increased, the equivalent strain values are larger around the nozzle area, the maximum equivalent strain zone appears at the later stage of nozzle forming (near the end of the nozzle forming), The maximum value of 1.69 and appear near the inner surface of the contact area between nozzle and billet, as shown in Fig. 6 (b).

![Figure 6. Billet equivalent strain distribution](image)

5. Results Comparison and Practical Application
According to Cockcroft&Latham fracture criterion [9-10], based on the analysis of the stress and the equivalent strain distribution, as can be seen, during the super pipe integrated pipe mouth forming, the most dangerous region occurs at the inner surface of the contact area of nozzle/billet, the area produced three direction tensile stress and has a greater equivalent strain. Therefore, this position is likely to crack. The actual production and inspection also proved that the area is most likely to produce cracks, as shown in Fig. 7.

![Figure 7. Comparison of simulation results with actual products](image)

In addition, the simulation results have been used to guide the formulation of process qualification scheme, such as the determination of the sampling plan, the feasibility analysis of the forming process and so on. For the weak position found by simulation, we should increase the test items, the number of samples, the overall dissection and other test methods to verify the overall quality of the steam pipe integrated nozzle, as shown in Fig. 8.
6. Conclusions
The simulation results show that each region near the nozzle has been axial and radial tensile stress during the whole forming period. The maximum axial tensile stress appears in the nozzle forming medium and produce in the nozzle connection transition zone near the inner surface. The maximum radial tensile stress occurs at the latter stage of the nozzle forming, and the maximum value appears in the nozzle region near the inner surface. The maximum equivalent strain occurs near the inner surface of the nozzle tip edge. According to Cockcroft & Latham fracture criterion, the dangerous area is located at the nozzle tip edge and connection transition zone of nozzle and main pipe. The actual product and inspection shows that there are cracks in these positions. It is necessary to increase the number of samples and test items to verify the overall quality of nozzle for the weak position.

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