Research on the Tight Fit Technology of New Fuel Element Based on Spinning Necking Forming

Zeming Wang[1,2], Jialong Chen[1], Xianmeng Tu[1], Xiaoyuan Ji[1,*], Jianxin Zhou[1]
1.State Key Laboratory of Materials Processing and Die & Mould Technology, School of Materials Science and Engineering, Huazhong University of Science and Technology, Wuhan 430074, PR China
2.Nuclear Power Institute of China, Chengdu, Sichuan, 610005, China
*Corresponding address: e-mail: jixiaoyuan@hust.edu.cn

Abstract: At present, based on the analysis of the failure characteristics of existing fuel elements, it is found that the failure of existing fuel elements focuses on the oxidation of the inner and outer sides of the fuel cladding, the bulging and bursting of the fuel cladding, the repositioning and diffusion of the fuel, and the melting of the fuel rod. The specific solutions are mainly through two aspects: first, enhancing the cladding of the fuel cladding, and second, improving the thermal conductivity uniformity of the fuel rod. The specific solutions include increasing the functional coating of the inner and outer walls Research and develop new high temperature resistant cladding, increase the height of fuel rod gas cavity, change from solid fuel pellet to annular fuel pellet, especially by enhancing the bonding quality of fuel cladding and fuel pellet interface, reducing the gap between them, so as to improve the cladding ability of fuel cladding, avoid the heat accumulation of fuel pellet and inner wall of cladding, and effectively improve the high sufficiency of single fuel rod High reliability is one of the most feasible solutions in engineering at present, and the close fitting technology between fuel cladding and fuel core is the ultimate success or failure of this process. Based on finite element simulation, this paper analyzes the forming process of the three roller spinning compression diameter, analyzes the radial and axial feed forming process of the roller, metal deformation behavior, metal flow and stress strain state during the forming process, and studies the control and optimization of the forming quality. On this basis, combined with the single fuel rod as the solid object, the spinning compression diameter tight fitting test research is carried out. Based on the test results, the development of special tight fitting equipment and process finalization are carried out. The results show that the best effect is to use the single pass small feed spinning compression diameter to coat the inner wall of the clad tube closely with the coating.

Keywords: Nuclear reactor, fuel element, cladding tube

1 Introduction

According to China's nuclear power mid-to-long term strategy, 4th generation reactors emphasize sustainability, non-proliferation, enhanced safety, and cost-effectiveness. Key designs include sodium, lead, and gas-cooled fast reactors, supercritical water ,ultra-high temp gas, and molten salt reactors, using coolants like liquid sodium, lead, helium, carbon dioxide, molten salts, and water. Despite varied reactor types and coolants, most employ rod fuel elements needing compatibility with liquid metals, high thermal conductivity, closed fuel cycles, and ample fission gas retention [1]. Modern fuel design trends towards optimized coolant flow, compact assemblies, and high-density fuels are pushing the envelope on existing fuel element technology[2].

Therefore, optimizing the fuel core-cladding bond boosts heat transfer, curbs radiation swelling, and bolsters safety in 4th generation reactor fuel, and has notable scientific and practical value.

2 Experimental procedure

The China Nuclear Power Research and Design Institute has independently developed CLA16, a low-activation FM stainless steel, matches T91, T92, CLAM, CLF-1 performance. Cladding OD: 12.02-12.06 mm, ID: 10.39-10.43 mm. Inner Cr coating via CVD (~15 μm). U-Zr alloy test fuel; Mo-W simulant pellets for research (OD: 10.340-10.355 mm) ensure ≤ 0.04 mm gap.

Based on this, taking the research on the tight fitting of new rod fuel elements as the main line, the numerical simulation re-search on the spinning necking tight fitting assembly was carried out. Investigation into cladding-pellet dynamics via spinning compression tests optimized parameters and facilitated specialized equipment development for single fuel rods, aiding full-scale product development and mass production.

3 Result and discussion

3.1 Numerical simulation and analysis of three roller spinning shrink fit assembly

At the beginning of the whole forming process of spinning and reducing, when the three spinning wheels extrude the clad tube radially, they exert a force on the clad tube, thus producing stress and strain. As a whole, only the relatively narrow necking area has large stress, and the equivalent stress is mainly distributed in the necking area, as shown in Fig. 1.

As can be seen in Fig. 2, the clad tube is deformed due to the radial extrusion of the spinning wheel, so as to achieve the effect of reducing. In addition, the area near the necking of the clad tube has almost no axial deformation, and the wall thickness of the clad tube is almost unchanged.

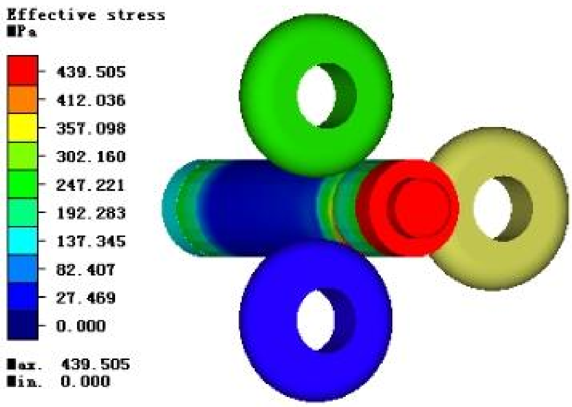

Fig. 1 Equivalent stress distribution in radial feed forming process of spinning wheel

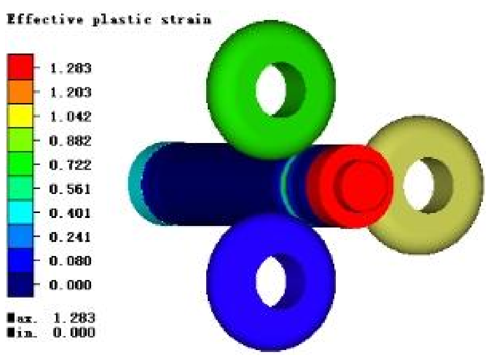

Fig. 2 Equivalent strain distribution in radial feed forming process of spinning roller

3.2 Experimental study on rotary spinning reducing process of single fuel rod

In order to better analyze the influence of different pass feed rates on the forming quality of this product and determine a reasonable feed rate distribution process experiment, this study conducted a total feed rate of 0.09mm, which was simulated in five groups, two groups for two passes, two groups for three passes, and one group for four passes.

Fig.3 shows the product forming effect under different feed rates. High feed rates prevent cracks but cause uneven gap distribution and minor radial bending.

3.3 Research and development of spinning reducing pro-cess equipment and sizing process for single fuel rod

Leveraging simulations and past tests, we'll optimize the spinning necking process for single fuel rods using a specialized roller rotation device, standardizing the tri-roller compression method, and statistically evaluating critical quality parameters to aid in single rod development.

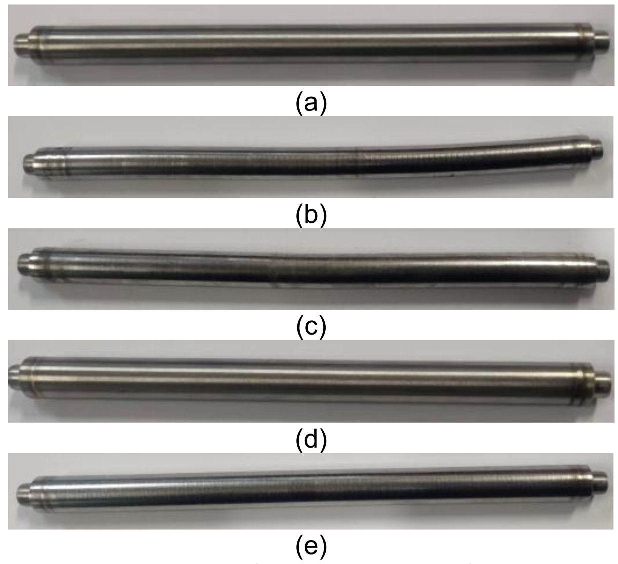

Fig. 4 Forming quality of each spinning wheel feeding mode

4 Conclusions

(1) Optimal settings (250 rpm, 0.03 mm spinning feed, 0.2 mm/s axial feed) in 1-2 passes ensure smooth rods, minimal deformation, and <15 μm max cladding-core clearance.

(2) Small-feed single-pass spinning effectively fits coated cladding tubes, preserving coating integrity without defects like peeling or cracking.

(3) Enhancements needed: NDT for clearance, batch production reliability, stress analysis, and precision straightening in new fuel element development.

5 Acknowledgments

This work is financially supported by National Key R&D Program (2020YFB1710100), Science and Industry Commission Project (2019XXX.XX4007Tm), and National Natural Science Foundation of China (52275337, 51905188, 52090042).

References

[1] Music O, Allwood J M, Kawai K. A review of the mechanics of metal spinning[J]. Journal of materials processing technology, 2010, 210(1): 3-23.

[2] Kwiatkowski L, Tekkaya A E, Kleiner M. Fundamentals for controlling thickness and surface quality during dieless necking-in of tubes by spinning[J]. CIRP Annals, 2013, 62(1): 299-302.