Superplastic forming and diffusion bonding the key parts for future fusion reactors

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INTRODUCTION:

Under the superplasticity forming (SF) condition, materials exhibit extremely high formability (can be even more than 2000%) without necking. This enables complex structure sheet components to be produced. Combined with simultaneous diffusion bonding (DB), complex hollow multicellular multilayer structures can be manufactured in a single step. The SPF/DB enables component design with significant increase in weight saving/functionalities while excellent structure integrity is maintained compared to other sheet forming technologies. SPF/DB is a relatively well-established process for manufacturing complex shaped part in the aerospace industry such as wing access panels, rudders, nozzles, engine casings and blades but almost exclusively from titanium alloy sheets.

With the recent advances of fusion reactor research, there is increasing interest in extending the applications of SPF/DB technology to stainless steel, nickel based superalloys and grade 91 alloy steel which are being considered candidate materials for the key fusion reactor components, such as heat exchanger where complex internal cooling channels are needed. SPF/DF seems a promising means to produce such complex shaped, multiplayers, safety critical components.

However, limited attempts/studies can be found in the literature on these potential materials, little is known about their feasibility of superplasticity and diffusion bonding ability. In particular, it is generally accepted that the diffusivity of Ni-Ni, stainless steel-stainless steel is very slow due to the presence of stable oxide layers, formed on the free surfaces. This research aims to study the feasibility of SPF/DF of these three candidate materials and provide the understanding of how to optimize the SPF/DB process for components design.
AIMS AND OBJECTIVES:

The main aim of the proposed research is to perform feasibility study for grade 91 steel, stainless steel and nickel based superalloys by identifying their SPF and DB processing window forming for high temperature Nuclear power plant applications. The specific objectives of the project are given below:

1. Identify the DB process window for all three candidate materials
2. Identify the SPF process windows for all three materials.
3. Examine the feasibility of SPF/DB for all three materials.
4. Determine the stop-off materials for DB
5. Understand the material microstructure evolution during SPF/DF
6. Examine their strength/structural integrity post SPF/DF process.
7. Evaluate the process regarding costs, productivities to give recommendation.

MAJOR TASKS

To achieve the objectives, the research programme has been divided into a number of distinct tasks, which are detailed below:

(1) Review and analysis of SPF/DB technologies for various materials for complex-shaped multilayer structures. Particular attention will be paid on (i) SPF/DB implementation for Niacle based super alloys; (ii) SPF/DB implementation on Stainless steel; (iii) SPF/DB for Grade F91 steel; (iv) productivity (related to tool temperature, cooling condition, forming condition etc). A review report will be generated which will short list the most suitable material (out of three) for further investigation of the implementation of SPF/DB technologies. 3 Months

(2) To estimate the approximate superplastic forming window, strain rate jump test will be performed using our Gleeble 3800 and the strain rate sensitivity of such materials will be determined. 1 Month

(3) Based on the conclusion of (2) the materials with feasible/unknown SPF and DB will be proceeded.

Prepare a progress report to UKAEA.

(4) To identify the optimal superplastic forming window, thermal-mechanical testing will be carried out on our Gleeble 3800 to obtain the flow stress and strain behaviour of a given material at forming temperature, approximately in range of diffusion controlled regime i-e 0.5Tm for different strain rates range determined from (3) ....... 5 month

(5) To ensure similar mechanical properties of the SPFed samples, post-SPF microstructure will be characterize by optical microstructure and EBSD to ensure similar microstructure (phases & grains) as the received materials 1 Months

(6) To identify the optimal diffusion bonding parameters, based on the results (4) and a set of two-rod-press diffusion bonding experiment at various temperatures, pressures, time and surface treatment will be performed. 6 Months
(7) To examine the bonding strength of DB samples, the diffusion bonded samples of (5) will be subsequently machined to tensile testing samples tested by (a) doing thermal mechanical tensile test at the service temperature and (b) by analysing the SEM micrographs at bonding interface.  

5 Months  

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(8) To find the suitable stop-off material for DB, various stop-off materials will be tested and their bonding strength at DB condition will be examined. For manufacturing multilayer complex shapes, there are regions which are not bonded and a stop-off material is applied. Combined with the diffusion bonding tests a series of experiments will be performed.  

5 Month  

(9) Carry out a small scale demonstration trial using the determined SPF/DB processing window and stop-off materials. The microstructure and mechanical properties will be determined. …  

4 month  

(10) Cost, productivity evaluation, industrial implementation, and complete the PhD thesis.  

6 months  

MANAGEMENT OF THE PROJECT  

Dr Jun Jiang and Professor Jianguo Lin, at Imperial College will be academic supervisors for the PhD student. The academic supervisors will interact with the student on a day-to-day basis and a formal meeting with the student will be held once a week. The industrial supervisor will give general guidance to the student, especially for applications of the process. Formal meetings will be held half-yearly, chaired by Dr Jiang, and all the people involved in the project will attend the meetings. The progress of the research will be reported to UK Atomic Energy Authority and a detailed research program for the next period will be reviewed and subject to modifications. Dr Jiang will spend 2 hours per week and Professor Lin 2 hours per week on the research project.