AIRCRAFT STRUCTURE TECHNOLOGY OF ADDITIVE MANUFACTURING

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Abstract

The technical advantages of additive manufacturing in the fabrication of large complicated fame-beam integral component are introduced, and the material-graded method is applied to obtain highly-efficient component whose static and fatigue performances are investigated. Besides, a multi-functional structure is detailed.

1 General Introduction

An aircraft structure requires light weight, high efficiency, long life, low cost, and rapid manufacturing [1]. Although it has been over half century since the jet engine aircraft was invented, the aircraft structure has not been developed too much. This is because the traditional manufacturing technologies, such as forging, casting, welding, milling, turning, and grinding, have not changed much. With these complicated technologies, manufacturing an aircraft has long been high-cost. Therefore, an innovative structure technology is needed. The birth of additive manufacturing (AM) provides an opportunity. With AM, large-scaled integral structure, material-graded structure, multi-functional structure can be expected.

2 Large-scaled Integral Structure

Obtaining a large-scaled integral structure was almost impossible in the past since it has to be manufactured by combining tens of thousands of components. However, if the part planes in design are eliminated, the redundant structures will also be involved in load transforming, which is preferred. But how can such a huge structure be fabricated? Since the strength and fatigue properties cannot be guaranteed by traditional manufacturing technologies such as welding, AM may provide a solution. The next question is how to avoid or control the deformation and crack such that the performance is achieved. Global discretization-partition optimization has been applied by the authors' research group to achieve forming and connection at the same time. Shown in Fig.1 is a typical airframe utilized in a fighter aircraft, which is manufactured integrally without any fasteners. The connecting is obtained through AM process instead of welding or fastening, whose properties is the same as the base material. As a result, both the stress concentration and structure-loading efficiency are improved significantly. It also benefits for the cost-saving of fabrication without relying on the traditional tools and fixtures. And such an AM technology can dispense the limitation of size.

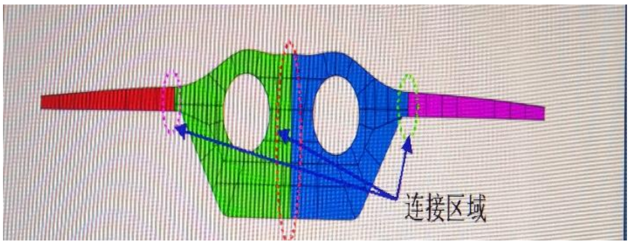

Fig.1. A typical airframe of fighter aircraft

In order to maximize the material performance, the research group proposed an equivalent K_t method for evaluating the fatigue performance of a structure. In forming connection, the mechanical properties are controlled by the parameters of forming process and heat treatment. The group proposed a set of testing steps to examine the components at three levels, namely small, medium and large, where the medium one is especially important. For a real typical component, passing the tests is not easy. Fig.2 is a part of an airframe utilized for the validation of fatigue performance compared with the result calculated form equivalent K_t method. The result illustrates that the static strength of connecting area is about 90% of original material, while the fatigue strength is over 85% of the base material.

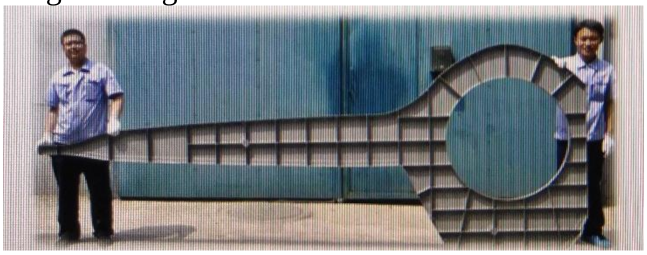

Fig.2. Half part of an airframe manufactured via AM

3 Material-gradient Structure

By AM, the component is fabricated with dissimilar metal material. In this way the gradient distribution of the mechanical properties is obtained, and the material graded structure is formed [2], [3]. The advantages are obvious. For instance, the material layout is designable, the lightening efficiency as well as fatigue life are improved, and the integration of load bearing, heat and corrosion resisting are complete. Three combinations of different materials, i.e., TC4+TC11, TA2+TA15, and 300M+A100 present in Fig.3.

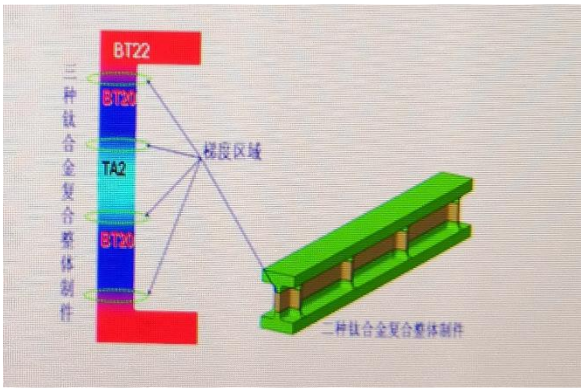

Fig.3. A gradient structure of different materials

The performance of the transition zone, including the geometric feature, specimen, static behavior, and fatigue behavior are investigated. An important issue for material graded structure is the design and assessment method. Two approaches are applied. The first one is to develop new elements, which is finished in collaboration with Beihang University of China. With new elements, the crack propagation life analysis is established. Another one is the multi-material layout optimization, which was complete in collaboration with Dalian University of Technology of China.

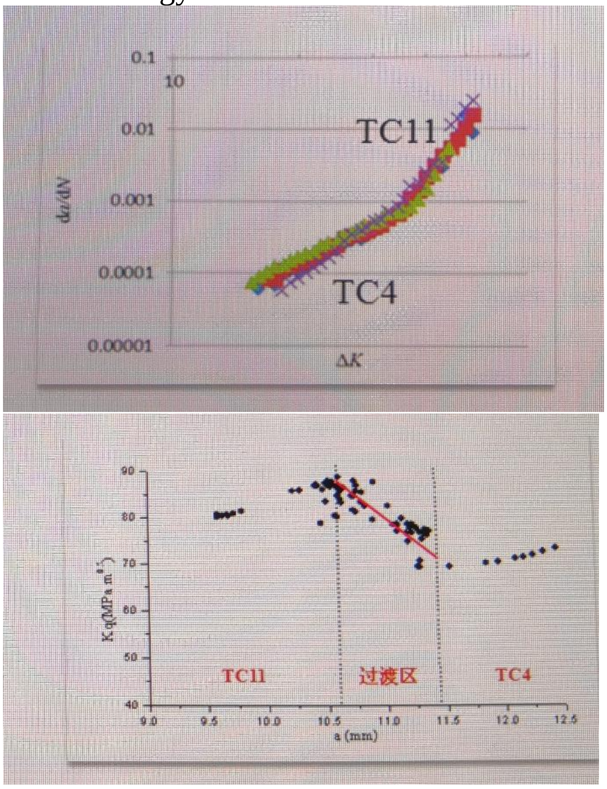

Fig.4. The fatigue performance of a multi-material layout

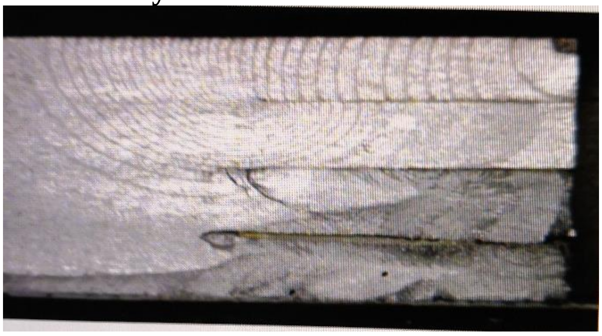

Fig.5. The interface crack of a multi-material layout

4 Multi-functional Structure

The functional system and fuselage structure are designed separately in the traditional structure, and the functional system is fixed on the fuselage structure [4], [5]. As a result, the design has some redundancies, and the weight increase is inevitable. By contrast, the fusion design in the functional integrative structure yields simple structure as well as light weight. The authors tried some metal multi-functional lattice structure fabricated by AM, which are actually the millimeter scale tresses where the optimal design of the unit cell configuration is one of the most important issues. From an engineer's point of view, the authors focus on the structural features, functional features, and process characteristics. To carry out the multi-constraint optimization, some issues must be solved, including load bearing characteristic, failure mechanism, failure modes, failure criteria and failure rules. Some experiments and testing are conducted by the authors. However, this is just the start. Within analyzing the failure modes of the metal multi-functional lattice structure, some results are shown. For example, under compression, the length of broken rods is approximately equal to the inti cell rods when the break occurs at the nodes. The reason is that the nodes yield first due to the highest stresses occurred at the nodes and breaking happens at the nodes after the buckling of the rods. The factors affecting the load bearing capability of a metal multi-functional lattice structure contain the unit cell configuration, the relative density of the structure, and the load types. The failure modes can be roughly categorized as plastic buckling, brittle fracture, connection fracture, and the buckling-based wrinkling of the panel. Five steps are observed in the compressive test, such as linear elastic, soften, contact, compaction and densification. Tit is also found that the relative density of lattice tress cores sandwich structure has a great impact on the compressive strength. Another test, the tensile test, is complete, which reveals that the load-displacement curve is very similar to that of the traditional metallic material. The observation in the three-point bending test indicates that the top panel yields before the bottom one.

5 Conclusions

Due to confidentiality requirement, the research briefly shows some engineering applications, including four crafts, eight materials, ten components, and a few model applications. AM is quite useful in solving three problems: the bottlenecks of structure design, rapid trial manufacturing, and innovation by creative idea.

It is worth being noticed that some research areas, including developing new concept structures, new failure modes and criteria, new modeling and analysis methodologies, multi-constraint optimization involving technological properties and functional constraints, simulation techniques of forming process, integral assessment methods for structures, and testing methods of functional integrative structures, are the future investigations.

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