LINEAR FRICTION WELDING – PROCESS DEVELOPMENT AND APPLICATIONS IN AEROSPACE INDUSTRY

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Abstract

Linear Friction Welding (LFW) is a solid-state joining process very well adapted to titanium alloys, producing high integrity joints with fine grain, hot-forged microstructure and narrow heat affected zone. The first industrial application of this process was found in aircraft engines, for the manufacturing of “blisks” (“bladed disks”): linear friction welding the blades onto a disk provides economic savings and reduces the manufacturing time, compared to machining the whole blisk from solid. While the diffusion of LFW process in the blisk manufacturing market is still at the early stages and have promising growth potential, the process is now being developed for aircraft structures such as clips, brackets, hinges, fittings, and larger parts like seat rails, wing ribs, lintels and fuselage frames. The LFW process allows not only to manufacture a given part at a lower cost, it also open new part design possibilities, that were not available with traditional manufacturing processes.

The manufacturing process of Ti-6Al-4V structural and engine parts by LFW is explained, highlighting advantages, limitations and part design best practices. Several LFW candidate parts are introduced and evaluated through feasibility, mass savings, post weld operations and overall cost savings.

I. Introduction

Linear Friction Welding (LFW) is a solid-state joining process involving the use of a linear reciprocating movement of two pieces under high contact pressure. The frictional heat locally softens the material, which is expelled from the interface due to axial load. As a consequence, an axial shortening of the components is observed. A forge phase ensues from the friction phase: oscillation motion is stopped; the two components are brought into perfect alignment and the welding force is maintained or increased to consolidate the joint.

The process is generally divided in 4 phases:

- Contact. The two parts are put in contact.
- Conditioning. The pressure is applied, and the oscillation motion starts. Temperature is not high enough to make the material flowing, but the irregularities of faying surfaces are rubbed.
- Burn-off. Pressure and motion are still applied, and the material is expelled.
- Forge. Oscillations are stopped and pressure is held during cool down.

Figure 1: LFW process phases

The process is control through four main parameters:

- Frequency of oscillation (30 Hz to 60 Hz)
- Amplitude (± 1 to ± 3 mm)
- Forge pressure (70 to 110 MPa)
- Upset (1 to 3 mm)

The values in parenthesis are typical values for Ti-6Al-4V.

The evolution of a typical LFW cycle is the following:

Figure 2: LFW typical cycle

LFW presents many advantages from metallurgical and mechanical aspects to economical point of view.

II. Process global advantages

First of all, LFW is a low temperature welding (for Ti-6Al-4V with a welded surface of 2000 mm² the temperature reached at the welding interface is about 1200°C, which is below the melting temperature of Ti-6Al-4V). It means, there is no melting of the parent material. So common problems associated with fusion welding such as solidification cracking, porosity and segregation are avoided.

In addition, LFW cycle time is very short: only two or three seconds of friction, and five to ten seconds of cooling down (to consolidate the welding joint) are necessary.

The combination of low temperature and short cycle time leads to low heat input, so small Heat Affected Zone (HAZ). In the nugget zone (welding joint), there is a Widmanstätten microstructure with very fine grains, close to hot forged microstructure.

Figure 3: LFW Ti6Al4V micrography

Regarding the static and dynamic behaviors (tensile and fatigue tests), LFW welds have properties very close to those of the parent material.

Besides, LFW is a self-cleaning welding. All the impurities or oxides which could be present at the interface are expelled with the flash outside the interface. Thus, the preparation of the welding joint is minimal and LFW can be done in open air, no gas shield is required.

LFW is also a process which is easy to automate and very repeatable. It is due to the fact that the only heat source is mechanical, so all the energy input is controlled by motion and loads.

III. LFW applications in aircraft engines

LFW has many advantages for the blisks (bladed disks) production which are mainly used for both compressors and fan blades rotors.

Currently, the three ways to manufacture blisks are:

- Mechanical dovetail assembly
- Solid block machining
- Linear Friction Welding (by welding the blade on the disk)

The advantages of LFW compare to machining for the blisks manufacturing are blatant as LFW allows buy to fly decrease (raw material savings from 20% to 30%), machining cost reduction and possibility to weld dissimilar material or hollow blades.

Besides, LFW process has also advantages compare to conventional mechanical assembly such as the hub diameter decrease and thus a global weight reduction. Moreover, with LFW there is no air leakage between blade and disk, thus, LFW allows a better compression efficiency and then fuel savings.

III. LFW Aero structural application

The important introduction of composites materials in aircraft structures has increased the need for titanium structural parts as titanium has a thermal expansion behavior very close to composite. This increase of titanium use induces many technical challenges particularly regarding raw material savings.

LFW is a process that allows both important aero structural parts costs savings (compared to classical manufacturing process such as full block machining) and very good mechanical and metallurgical behavior (close to those of parent material).

Indeed, LFW manufacturing induces additional costs relative to the flash machining, non-destructive inspection (ultrasonic testing), heat treatment or the welding operation itself.

Nevertheless, all these additional costs remain negligible compare to machining and raw material costs induced by conventional manufacturing processes (full block machining).

Over the past last years, ACB has developed LFW of aero structural parts and is now the first company qualified by AIRBUS and BOEING for the LFW manufacturing of titanium parts.

Figure 4: T clip and seat rails manufactured by ACB using LFW

Figure 5: ACB LFW aerospace demonstrator (from left to right: after LFW operation, half machined, totally machined)

LFW allows several welding configurations. ACB has already welded the following geometries:

Figure 6 LFW weld configurations

Figure 7: L profile with 3 gussets (welded simultaneously), U profile

Besides, for many other structural parts, ACB is able to combine LFW with forming process such as Hot Forming or Hot Stretch Forming in order to further optimize the manufacturing part cost.

Figure 8: door frame demonstrator manufactured using both HSF (Hot Stretch Forming) & LFW technologies

The following example is a Ti-6Al-4V bracket manufactured using both Hot Forming (HF) and LFW:

Figure 9: L profile ("Bracket") manufactured using LFW & HF

The business case analysis of this part brings into relief that the combination of HF and LFW allows a raw material savings of about 12 kg, to divide the machining cost by 1.5 and overall savings of 36%.

IV. Conclusions

Thanks to its low cycle time (2 to 3 seconds of friction and 10 seconds of cooling down), high weld quality with static and dynamic behavior of Ti-6Al-4V very close to those of the base material and high repeatability, LFW is a process that is particularly interesting for the manufacturing of engine or aero structural parts.

Indeed, by welding near net shape parts LFW allows important mass savings, reduction of machining costs and thus important overall cost savings.

References

- [1]. P. Wanjara and M. Jahazi, Linear Friction Welding of Ti-6Al-4V: Processing, Microstructure, and Mechanical-Property Inter-Relationships (Metallurgical and Materials transactions, 2005)
- [2]. M. M. Attallah, M. Preuss, and S. Bray, "Microstructural development during linear friction welding of titanium alloys," *Trends Weld. Res.* 2008, pp. 486–491, 2009.
- [3]. Bhamji et al., I. Bhamji, M. Preuss, P. L. Threadgill, et A. C. Addison. Solid state joining of metals by linear friction welding : a literature review. Materials Science and Technology, 2011.