Friction stir welding opens up a new field: wide and thin aluminium panels

J. Backlund, A. Norlin, Å. Andersson

The mechanical properties and low distortion attainable with Friction Stir Welding make it possible to produce wide, thin gauge sections in aluminium in a way that has not been possible until now. The method allows for production of wide panels with mechanical properties approaching parent-metal strength. Compared to fusion welding FSW is a clean and environment friendly process. Some examples are presented that shows some of the rapidly growing field of FSW applications. The transport industry has been very active in utilising this new technology and has identified the considerable potential of FSW in weight-reducing designs. The 65 MN press at Sapa is highly suitable for producing thin-walled extrusions to be welded into wide sections. In direct connection to the press-line, a new FSW equipment for long-length, wide sections has been installed. This, in combination with a thorough knowledge in extrusion technology, extrusion design, and five years of industrial experience of FSW, puts Sapa in the forefront when it comes to production of wide and thin aluminium sections and panels.

INTRODUCTION

Friction Stir Welding (FSW) is a young process ideal for joining of aluminium extrusions. Two aluminium components are joined together by a rotating cylindrical tool, which is moved along the joint line. The process is described in detail in a number of reports (1,2).

Sapa started already in 1994 to develop the process for various applications. The focus during the first years was on manufacturing of components, which partly has been presented in other reports (3,4). With four production lines now in operation, the company has taken a forefront position in Friction Stir Welding.

Sapa is one of the leading groups in Europe for aluminium extrusions. The annual production is about 180000 tonnes in 22 presses. The largest press, P5 in Finspång Sweden, inaugurated in 1997, can produce sections up to 400 mm wide. With the new FSW-technology it is not only possible to manufacture wide sections but also large panels up to about 3 m in width.

PROCESS DESCRIPTION

Friction Stir Welding is a process in which a rotating, cylindrical tool with a shoulder and a central pin is forced down between the pieces that are to be welded. The workpieces must be firmly clamped to a very stable backing. The rotating tool is plunged down and after the material close to the tool has been sufficiently heated by friction and has become plasticized, the tool is moved along the joint. The motion of the tool creates a moving column of hot metal that consumes the weld interface, disrupting and dispersing aluminium surface oxides. The metal is forced around and behind the tool and the pressure build-up under the shoulder creates a void and crack free weld. The process is a solid state process without any melting of the material being welded. During the years, the Friction Stir Welding process has proven to be a straightforward and stable process once the welding conditions are set.

Jan Backlund, Anders Norlin, Åke Andersson, *Sapa, Sweden*

Memoria presentata a 4th World Congress Aluminium 2000, Brescia

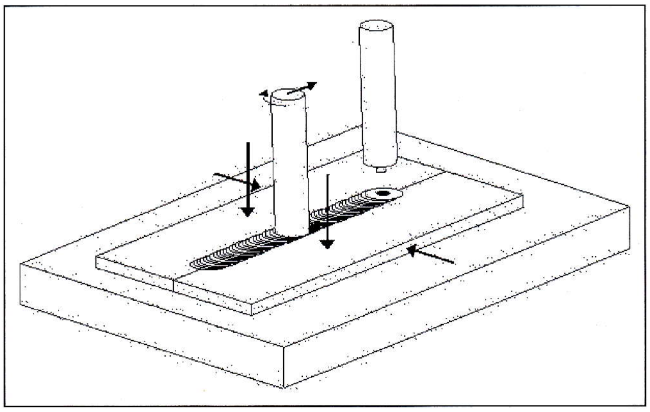

Figure 1: Principles of Friction Stir Welding.

SOME WELD PROPERTIES

Distortions

An important advantage with FSW is the low residual stresses (6,7). Within the fully recrystallized zone, they are effectively zero and seem never to exceed half the yield strength of the welded material, which is considerably less than the stresses often created by fusion welding. Sapa's experience is that it is possible to produce very flat panels with a minimum of distortion. The temperature history of the material in, and close to, the weld has been reported elsewhere (3).

In order to minimise the effect of the heat input, it is important to keep the temperature of the workpieces as low as possible during welding and to have very rigid clamping devices and backing. This is a core theme for all Sapa's welding equipment. Details concerning production of panels with high demands on flatness has been reported (4). In some special cases, however, the residual stresses are not negligible and steps have to be taken to compensate for them. The customary distortion control associated with fusion welding is of good use also with Friction Stir Welding. Most important, however is to learn to recognise potential distortion sources already at the design phase and take action to avoid future problems.

Fatigue strength

The weld seam of heat-treatable alloys has a somewhat de-

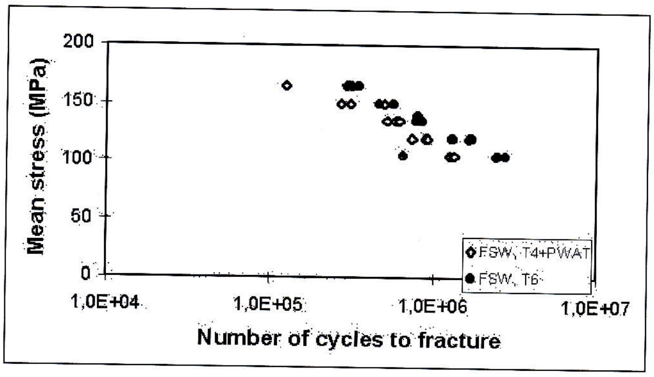

Figure 2: Results of fatigue testing. Mean stress vs. life for the two tempers T6 and T4+PWAT (5). The stress ratio R was 0.5, and a sinusoidal curve function was used.

creased strength in welded material. An interesting possibility to increase the strength when welding heat-treatable alloys using FSW is a post weld ageing treatment (PWAT). A product containing FSW joints can be "re-aged" and especially the solution heat treated material in the centre of a weld can reach yield and tensile properties close to those of the base material in the T6 condition (3).

A study has been carried out to establish the fatigue strengths of FSW welds in AA6082-T6 and AA6082-T4 plus PWAT (5). The material was welded in the T6 and T4 tempers. For T4 + PWAT the fatigue strength is somewhat lower than for T6, and with a steeper slope of the stress-life curve, (Fig. 2). In general, materials with high static strength also have increased high cycle fatigue strength. Since the crack in T6 propagates in softer material this may delay the propagation process through blunting. The T4 + PWAT condition, on the other hand, does not show a hardness decrease and instead other critical factors may influence the fatigue strength (5).

INDUSTRIAL APPLICATION

About two years after joining the first Friction Stir Welding project at TWI in 1994, the method was industrially established at Sapa. The first commercially manufactured product in the world using Friction Stir Welding was a panel for quick freezing units onboard fishing vessels (3)

The very promising results from this product opened up for production of a wide range of components using Friction Stir Welding. The welding equipment chosen from the start was a 5-axis bed-type-milling machine with a table size of 1000 x 4000 mm, (Fig. 3). The experience obtained from this early machine has provided a basis for designing the new long-length welding line.

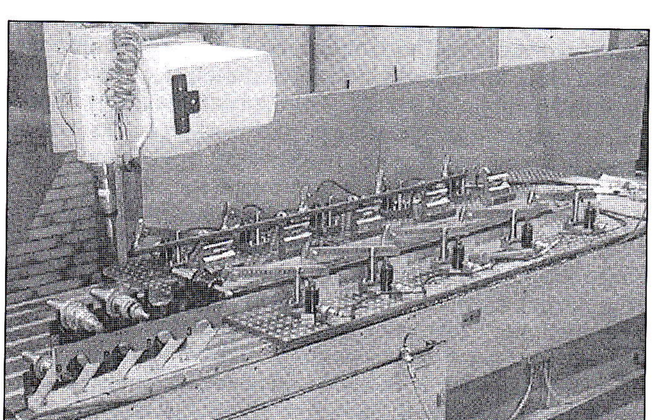

Figure 3: Sapa's first FSW equipment used for both components and wide profiles with a length of max. 4 meters.

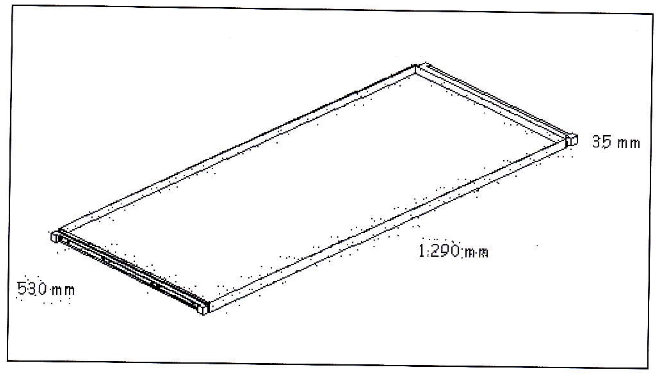

Figure 4: Original design of tray for freeze-drying in food industry.

Product cases

Tray for freeze-drying in food industry.

This case is a typical example showing how wide and thin profiles joined by Friction Stir Welding can improve the function, reduce the weight and keep the cost at an acceptable level. The original design was a plain tray of aluminium sheet material with profile end-fittings, (Fig. 4). The customer wished to improve the heat transfer between the tray and the foodstuff in order to get a more uniform quality and to increase the productivity.

Calculations and practical tests showed that replacing the sheet with a finned profile should provide the desired increase in heat transfer to the substance to be freeze-dried. The weight however of a single extruded profile would be considerably higher than the existing solution, which was not acceptable.

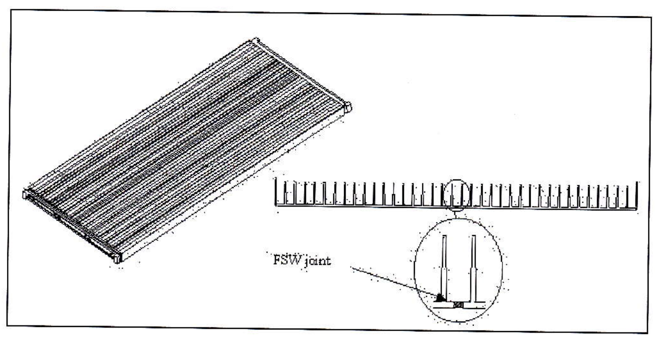

Figure 5: Final design of tray for freeze-drying incorporating FSW joining of two thin-walled profiles.

The final design that fulfilled both the demands was a solution in which two profiles were welded together using FSW. The fact that the 65 MN press at Sapa is very well suited to produce both wide and thin-walled profiles was of vital importance for this decision. Compared to an alternative with a single large extruded profile the weight is about 60% less and the weight tolerance can be kept within ± 5%. The Friction Stir Welding of this product has proven to be efficient and technically superior to the other discussed solutions.

Thin panel for rolling stock

Panels produced by FSW must not necessarily have a flat shape. In fact, Friction Stir Welding provides new possibilities to create very complex shapes by welding two or more profiles together. The limiting factors are the machine and fixture design.

The extrusion showed (Fig. 6) is meant for ceiling panels and represents an example of a welded panel having a curved shape. Profiles for indoor use are often coated with paint and generally it is desirable that the joint line should be invisible after coating, which in most cases implies that

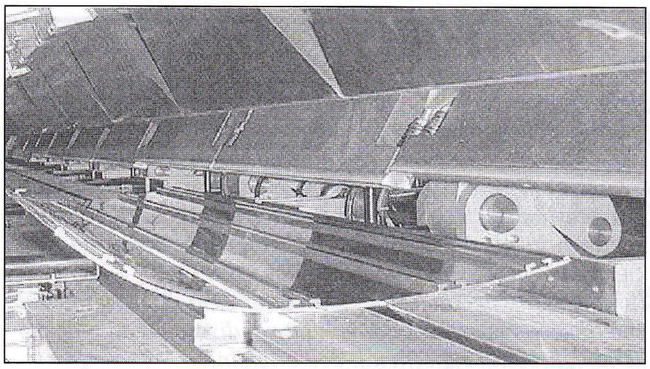

Figure 6: Example of Friction Stir Welded thin panel with curved shape.

efforts are taken to give the joint line a finishing treatment before coating.
The design of the fixture and clamping devices is of vital importance for the finished joint appearance. The thinner the material, the more important it is to arrange a proper clamping in order to keep the joint ends in close contact to the backing. The Friction Stir Welded joint has a flat root surface characterised by the surface imprint from the backing bar. By selecting a surface structure of the backing that resembles the current profile surface, the root appearance can often be used without any finishing treatment. The present profile needs no grinding or other surface treatment before painting. By using a powder coat with a slight surface structure the joint line will be almost invisible.

WELDING LONG, WIDE AND THIN

High quality welds can be produced in very straightforward equipment. However, some of the welding parameters are critical and must be carefully controlled. The fixture and clamping used must be very powerful and exact. The profiles to be welded need to be designed with FSW in mind. A close co-operation between profile design departments and FSW welders will facilitate the process.
The new long-length FSW machine was designed to weld 14,5 m long panels. This is the maximum length that is presently possible to handle automatically in the auxiliary units belonging to the 65 MN press, such as stacking and ageing equipment. The welding machine is placed in line with the material flow from the presses in the Finspång plant in order to create an effective system with a minimum of handling and waiting time.
The machine is fitted with three welding heads, two from above and one from below. This makes it possible to weld from both sides at the same time. In addition, it is possible to weld from one side only while still maintaining high productivity. During the process, the quality of the welds is checked both with video cameras and with an automated process- parameter control and monitoring system. After welding, the panels are cut to length in an automatic saw line. This equipment can handle panels with a width of up to 3 meters.

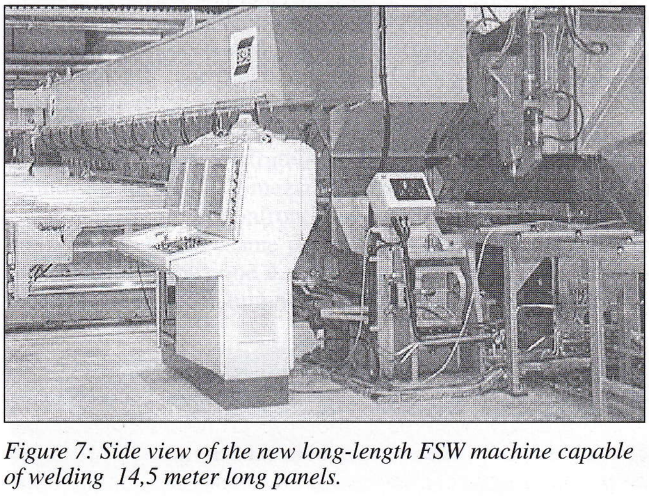

Figure 7: Side view of the new long-length FSW machine capable of welding 14,5 meter long panels.

Friction Stir Welding has gained rapid acceptance in the marine industry for the joining of aluminium alloys. Classification societies such as Lloyds Register of Shipping (LR) have kept track of technological developments and now approve the process for limited applications. As such, LR has produced guidance notes for its surveyors, which outline what a surveyor should be aware of when inspecting a manufacturing site and/or product (8). The guidance notes provide scope for new developments in the field that will allow manufacturers to utilise state of art technology.

CONCLUSIONS

FSW is an established process, with several units producing a variety of products from small components to large panels. The new press, P5 in Finspång, with a total press force of 65 MN makes it possible for Sapa to produce not only wide (400 mm) but also thin extrusions. As both the ageing furnaces and the new FSW-machine accepts 14.5 m extrusions, there now is excellent possibilities to manufacture long, wide and thin panels.
The new FSW equipment can handle both massive and hollow profiles. Special fixture and clamping arrangements can be designed for producing curved shapes within certain limits. The three welding heads, independently controlled, represents a significant step forward in the automation of the process.

REFERENCES

1) Thomas, Int. Patent Application No. PCT/GB92/02203, 10 June, 1993.
2) Thomas, Dawes, Gittos, Andrews, TWI Bulletin, Vol. 39, May/June, page 44-50, (1998)
3) Andersson, Norlin, Backlund, "IBEC'97", Adv. Techn. and Processes, page 105, Stuttgart, Germany, (1997)
4) Backlund, Norlin, Andersson, "INALCO'98", Session 5, page 171, Cambridge, UK, (1998)
5) Ericsson, Sandström, "To be presented at ICAA-7", Charlottesville, USA, April, (2000)
6) James, Mahoney, Waldron, "First Int. Conf. on Friction Stir Welding", Session 6, Thousand Oaks, CA, USA, (1999)
7) Chao, Qi, "First Int. Conf. on Friction Stir Welding", Session 4, Thousand Oaks, CA, USA, (1999)
8) Przydatek, "First Int. Conf. on Friction Stir Welding", Session 2, Thousand Oaks, CA, USA, (1999)

ABSTRACT

LA TECNICA DI "FRICTION STIR WELDING" APRE UN NUOVO CAMPO DI APPLICAZIONE: PANNELLI DI ALLUMINIO SOTTILI DI GRANDI DIMENSIONI

Le proprietà meccaniche simili a quelle del metallo originale e la bassa distorsione raggiungibili con la tecnica di "friction stir welding" (FSW) permettono di produrre pannelli in alluminio sottili e di grandi dimensioni, applicando questa tecnica altamente innovativa.
In confronto alla saldatura per fusione FSW si presenta come un processo ecologico e pulito. Nella presente memoria vengono accennati alcuni esempi dei campi di applicazione della tecnica di FSW, campi che sono in rapido aumento.
L'industria dei trasporti è stata da subito molto favorevole all'utilizzo della nuova tecnologia ed ha riconosciuto le grandi potenzialità di impiego per SFW specificatamente sul versante della riduzione di peso delle strutture.
Nel dettaglio FSW è un processo che si avvale di un utensile rotante e cilindrico, con una spalla e un perno centrale, che viene spinto fra le pareti che devono essere saldate, preventivamente fissate saldamente ad un supporto molto stabile.
La rotazione dell'utensile provoca, per attrito, il riscaldamento o la plasticizzazione del materiale vicino ad esso, mentre viene spostato lungo la giunzione.
Il movimento dell'utensile crea un afflusso di metallo caldo che investe l'interfaccia di saldatura, disgregando e disperdendo gli ossidi superficiali dell'alluminio.
Il metallo viene forzato intorno e dietro l'utensile e la pressione sotto la spalla crea una saldatura esente da vuoti e cricche.
Il processo avviene quindi tutto allo stato solido, senza fusione del materiale da saldare. Nel corso degli anni, il processo di saldatura FSW si è rivelato affidabile, una volta fissate le condizioni da saldatura.