



FOGNINGSCENTRUM / CJS

Centre for Joining and Structures



Cross-functional and directed research projects within “Centre for Joining and Structures”

General knowledge projects within:

- New processes – New materials
- Optimization – Evaluation – Simulation – Testing
- Increased understanding – Mechanisms – Models

Main application areas with projects within...

... automotive industry: thinner materials ex BiW, hang-on parts	... heavy industry: thicker materials ex dumpers, bridges	... stainless steels: ex power generation, tubes & pipes
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Hybrid joining of thermoplastics to aluminium.

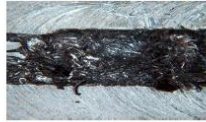


Wallop Ratanathavorn, Swerea KIMAB/KTH

Friction Stir Welding creates a joint by forming a volume with aluminium chips which is filled with molten thermoplastic

Tensile strength similar to adhesive bonding

Top view



Section through joint



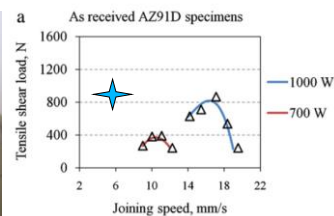
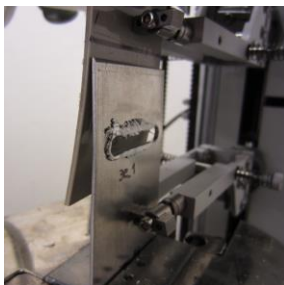
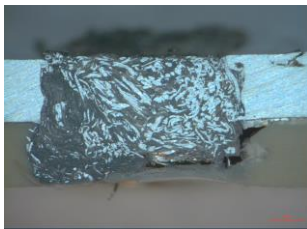
Failure in tensile test



XPR
Initiative for excellence in production research

swerea
swedish research

Friction Stir Joining of hybrid joints

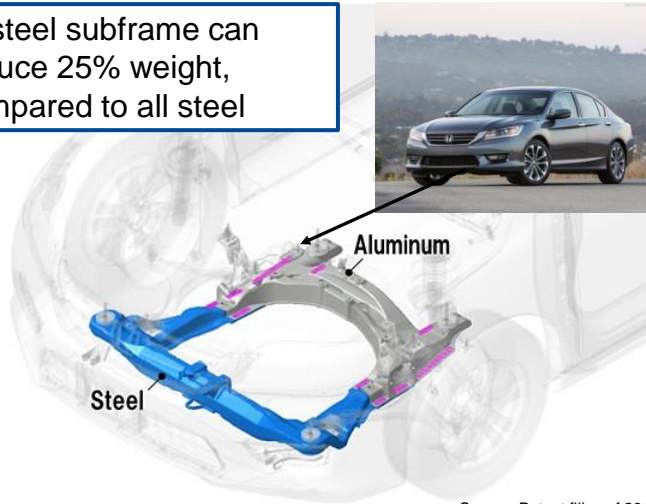


XPR
Initiative for excellence in production research

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swedish research

Al-UHSS Hybrid Structures by FSW

Al-steel subframe can reduce 25% weight, compared to all steel



Source: Patent filing of 2013 Honda Accord

swerea | KIMAB

swerea

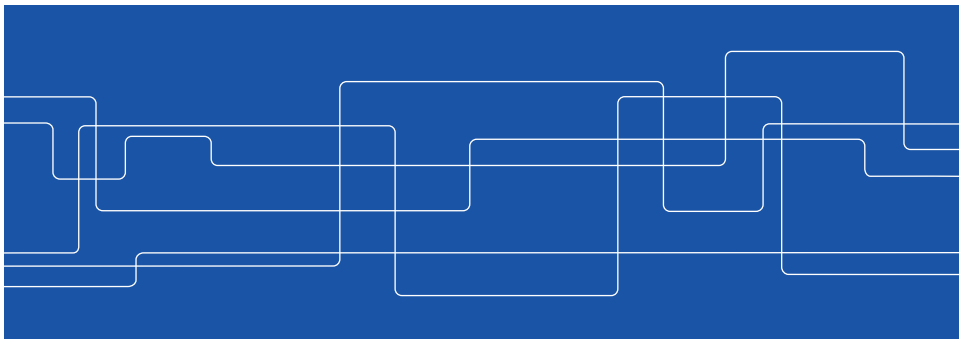


KTH ROYAL INSTITUTE
OF TECHNOLOGY

Dissimilar joining of aluminium to ultra-high strength steels by friction stir welding

Wallop Ratanathavorn

Department of Production Engineering





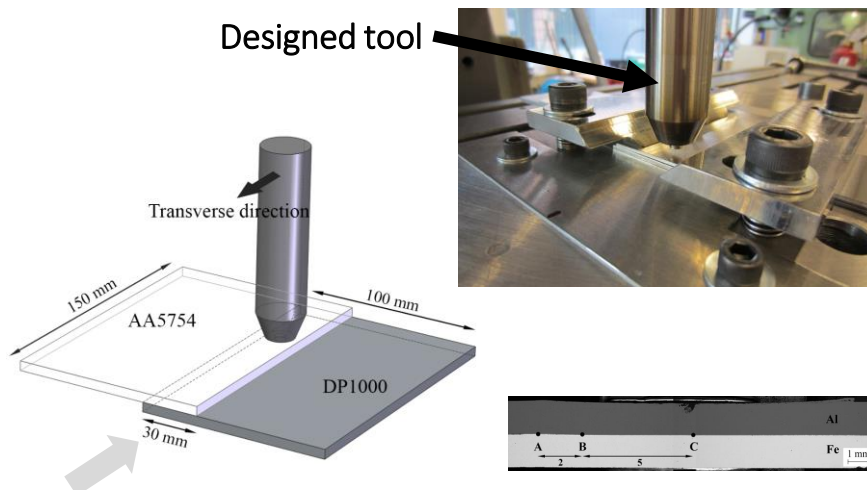
Introduction to the Dissertation

- ❑ To develop the welding technique for joining of dissimilar materials between aluminium alloy and steel,
- ❑ To increase the understanding of the effects of welding parameters, intermetallic phases at the reaction layer and third low melting material on the weldability and microstructures
- ❑ The joining technique is based on “**Friction Stir Welding**”
- ❑ Specimens were joined by overlap joint configuration.

7



A Quick Look of the Welding Process



8



Research Questions

1. Is it possible to friction stir weld aluminium alloy to steel with ordinary tool steel?
2. What are the effects of welding parameters on microstructures of joints and their performance?
3. What are the mechanisms of weld formation when the low melting materials like zinc are involved in the welding process?

9



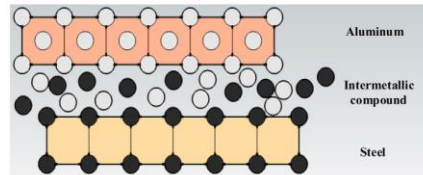
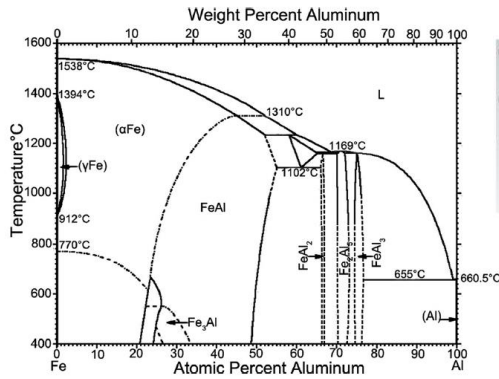
Hypotheses

1. Friction stir welding (FSW) with an ordinary tool steel can produce sound dissimilar joints between aluminium alloy and steel.
2. Low heat input as a result of fast translational speed and slow rotational speed produces a joint with thin intermetallic layer and accordingly high strength.
3. Zinc can improve the weldability of friction stir welded joint of Al/Fe by stimulating the chemical bonding between the aluminium and the steel base materials.

10



Phase Equilibria and Al-Fe System



Alloy vs Intermetallic

$\text{Al}_{13}\text{Fe}_4$: 820 HV

Al_5Fe_2 : 1100 HV

Used tool: 570 HV (harden)

11



Experimental Method

Setup



Tool



Uddeholm H13 Tool steel

Hardness: 53 HRC

12



Materials and Welding parameters

Parameters	Paper A	Paper B	Paper C	Paper D
Aluminium	AA5754	AA5754	AA5754	AA5754
Steel	DP800	DP800	DP1000	DP1000
- Surface coating	HDG	HDG	None, HDG	EG
Translational speed (mm/min)	60	40-80	40-160	40-160
Rotational speed (rpm)	1000-3500	1000-3500	1800	1800
Tool tilt angle (°)	2°	2°	2°	2°
Control mode	Position	Position	Position	Position

13



Results and Discussions

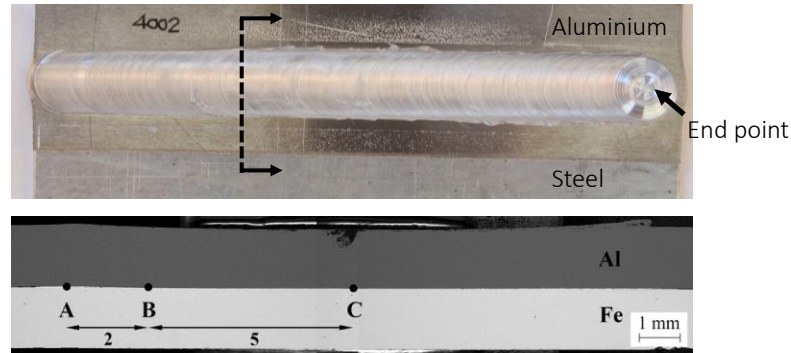
- Typical joint appearance
- Influence of welding parameters on the microstructure and joint performance
- Intermetallic phase formation
- Thermodynamics of intermetallics
- Role of zinc on joint characteristics
- Fracture surface

14



Typical Joint Appearance

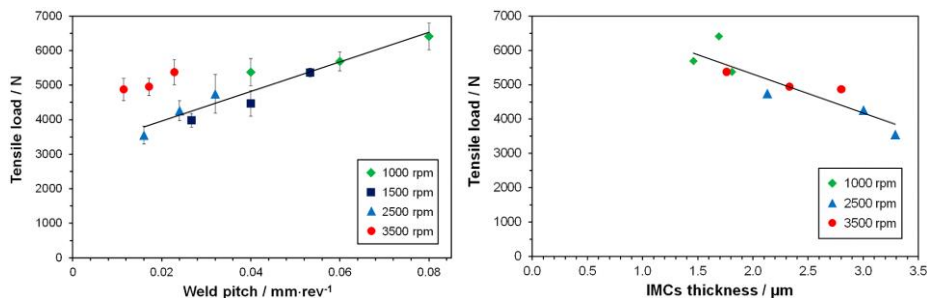
- Smooth surface appearance without flash on the aluminium side
- Macro-defects are not detected in cross-sections



15



Influence of welding parameters on the microstructure and joint performance

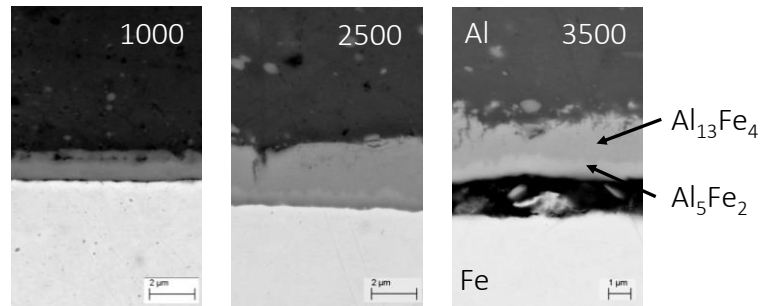


- Weld pitch is the ratio between translational speed/rotational speed or an inverse of heat input
- High weld pitch welding experiences a low temperature welding – thinner IMCs

16



Intermetallic Phase Formation

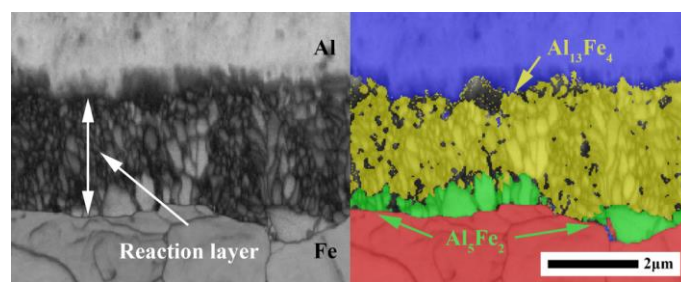


- EDS and XRD analysis confirmed $\text{Al}_{13}\text{Fe}_4$ phase on the aluminium side and Al_5Fe_2 on the steel side
- The $\text{Al}_{13}\text{Fe}_4$ layers are highly dependent on the value of rpm. While the Al_5Fe_2 layers are of comparable thicknesses.

17



Intermetallic Phase Formation (EBSD)

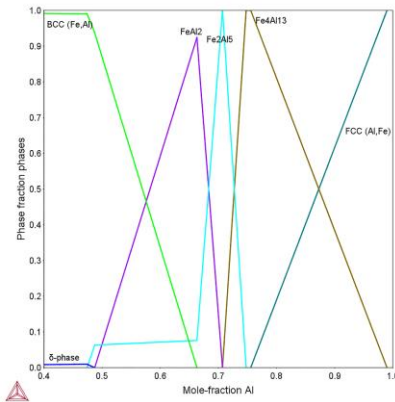


- The major phase is $\text{Al}_{13}\text{Fe}_4$
- Grains of the Al_5Fe_2 phase are larger than the $\text{Al}_{13}\text{Fe}_4$ phase
- No tongue-like morphology is observed on the steel side
- Smooth interface of reaction layer/steel

18



Thermodynamic of Intermetallics



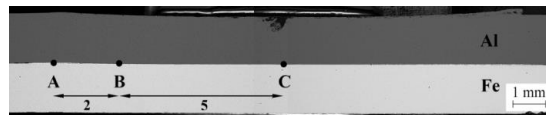
- The calculated equilibrium phases are Al_2Fe , Al_5Fe_2 , $\text{Al}_{13}\text{Fe}_4$
- Only two phases, Al_5Fe_2 , $\text{Al}_{13}\text{Fe}_4$ are detected in this research work
- The possible explanation by Naoi et al. described that some Al-Fe IMCs may be thermodynamically stable but they cannot grow to a significant thickness because of the very low growth kinetics

At Al corner with 1 at.-% zinc at isothermal temperature of 450 °C

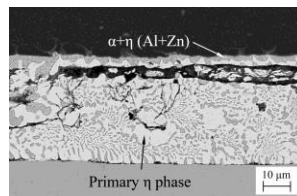
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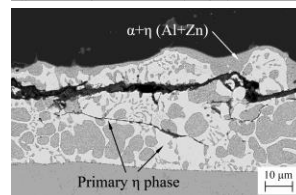
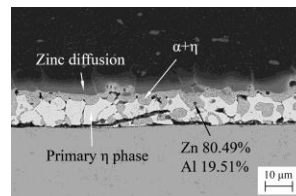
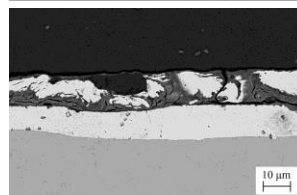
Mechanisms of Weld Formation (with Zn)



8 μm HDG



14 μm HDG



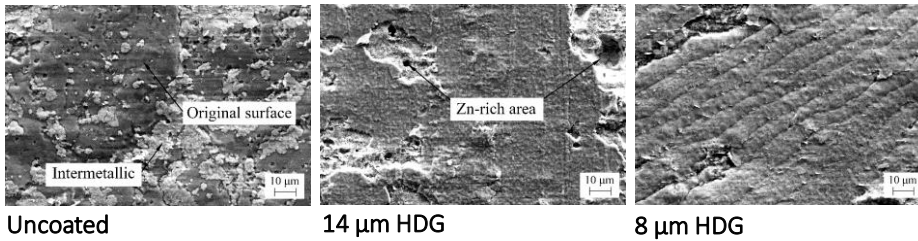
80 mm/min
1800 rpm

20



Fracture Surface

Fracture surface on aluminium side at 160 mm/min



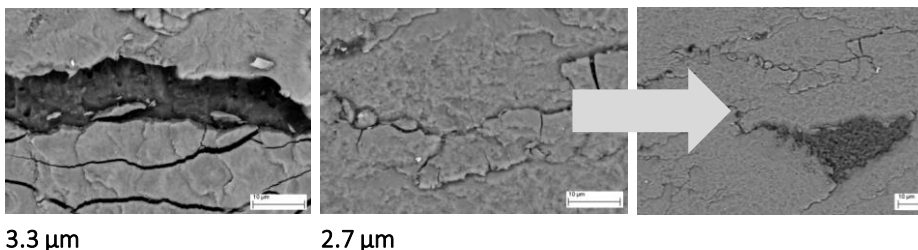
- A large unbonded area with small area of IMCs
- Zn-rich area (build up) that can degrade joint strength

21



Fracture Surface (Thick vs Thin IMCs)

Fracture surface on aluminium side



- Broken apart of intermetallic layer
- Intermetallic layer still adheres on the aluminium matrix
- Deformed (ductile) fracture can be detected in some area

22



Conclusions

1. Fully strong joints where fracture went through the aluminium base material were obtained.
2. Translational speed and rotational speed influence joint microstructures and accordingly mechanical properties.
Low heat input welding (high weld pitch) reduce the risk of brittle behaviors of the intermetallic phases

23



Conclusions

3. Zinc promotes the atomic bonding between Al and Fe especially at low heat input welding.
Better intimate contact between the Al matrix and the steel >> Increase nucleation and/or growth of the reaction layer
4. Two Al-Fe IMCs, Al_5Fe_2 and $\text{Al}_{13}\text{Fe}_4$, were formed at the interface.
In good agreement with thermodynamic calculations, although the welding process has relatively short cycle time compared to equilibrium conditions

24



Conclusions

5. Welds are formed by a lateral extrusion of the molten zinc layer by the pressure of the tool. The process leaves a fresh interface of steel to react with the aluminium alloy resulting in the reaction layer containing intermetallics. Melting of the zinc layer is done through melting of pure zinc or formation of the eutectic mixture of Al-Zn.
6. Intermetallic phase exhibits a columnar growth due to an anisotropic diffusion in the direction perpendicular to the Al-Fe interface.

25



Thank you!

