Friction Stir Welding
Varjenje z gnetenjem

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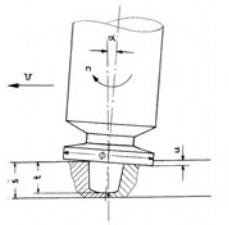
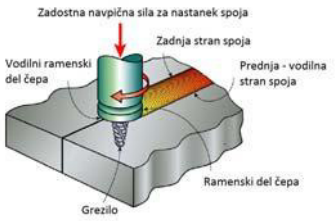
FSW varjenje

- termomehanski postopek spajanja, kjer se rotirajoči gnetilni čep s konstantno hitrostjo pomika po reži med dvema varjencema.
- Zaradi trenja med materialom in ramo orodja se ustvarja toplota, ki spoj močno ogreje, material se omehča, grezilo orodja pa ustvarja mešanje materiala spoj.





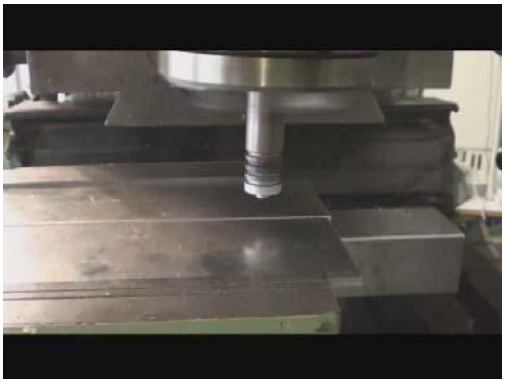
TWI Anglija, varjenje Al

Varjenje hladilnika

Varjenje Al + Cu

GKSS, pokrov rezervoarja iz Mg

Fakulteta za strojništvo, Univerza v Ljubljani



FSW varjenje v primerjavi s talilnim varjenjem

PREDNOSTI

- Možnost spajanja materialov, ki se težko spajajo z obločnimi postopki (aluminijeve zlitine 2xxx, 7xxx, Mg, Cu.
- Dodajni material in zaščitni plin nista potreben
- Spajanje različnih materialov med seboj.
- Majhne deformacije.
- Brez dodatne obdelave spojev.
- Enostavna in cenena priprava zvarnih robov.
- Brez iskrenja, dimnih plinov in sevanja.
- Dobra ponovljivost.
- Dobre mehanske lastnosti spoja.
- Možno varjenje v različnih legah varjenja.
- Orodje se ne izrablja (1 km var Al 6000).
- Sprejemljive tanke oksidne plasti.
- Možnost avtomatizacije in robotizacije postopka

BENEFITS

- the ability to join materials that are difficult to fusion weld, for example, 2XXX and 7XXX aluminium alloys, magnesium and copper.
- suitable for automation and is adaptable for robot use.
- Low distortion and shrinkage, even in long welds
- Excellent mechanical properties in fatigue, tensile and bend tests
- No arc or fumes
- No porosity
- No spatter
- Can operate in all positions
- Energy efficient
- One tool can typically be used for up to 1000m of weld length in 6XXX series aluminium alloys
- No filler wire required
- No gas shielding for welding aluminium
- Some tolerance to imperfect weld preparations thin oxide layers can be accepted
- No grinding, brushing or pickling required in mass production
- Can weld aluminium and copper of >75mm thickness in one pass.

FSW varjenje v primerjavi s talilnim varjenjem

SLABOSTI

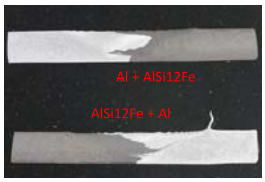
- Togo vpetje (velike sile).
- Potrebna podpora pod varom (razen če uporabljamo bobbin tool).
- Izstopna odprtina po koncu varjenja.
- Slabša prilagodljivost (različne debeline varjencev, različna orodja).

DISADANTAGES

- Higher welding forces – clamping
- A support under the tool is needed - exception Bobbin tool
- Hole at the end of the weld
- New tool is needed for each sheet thickness.

Varimo lahko / welding can be done on

- Aluminum alloys (2xxx Al Cu, 5xxx Al Mg, 6xxx Al Mg Si, 7xxx Al Zn, 8xxx Al Li, ter 1xxx Al, 3xxx Al Mn, 4xxx Al Si, ulitke castings,
- Cu in Cu zlitine (alloys),
- Ti in Ti zlitine (alloys),
- Svinec
- Mg (lead),
- Polimere
- Jekla (steels)(ogljikova, nerjaveča, nikljeve zlitine)
- Različne materiale med seboj (joining of disimilar materials)



FS LJ

Debeline varjencev v enem prehodu
Al > 50 mm (75 mm Al – 6000 TWI)
Cu do 50 mm

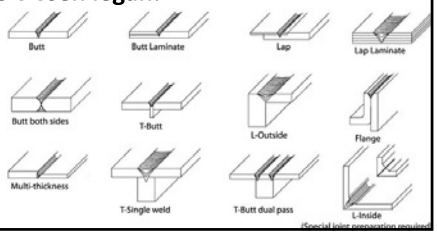
Geometrije varov

- sočelni spoj,
- prekrovni spoj,
- T – spoj z enim ali dvema zvaroma
- vogelni spoj.

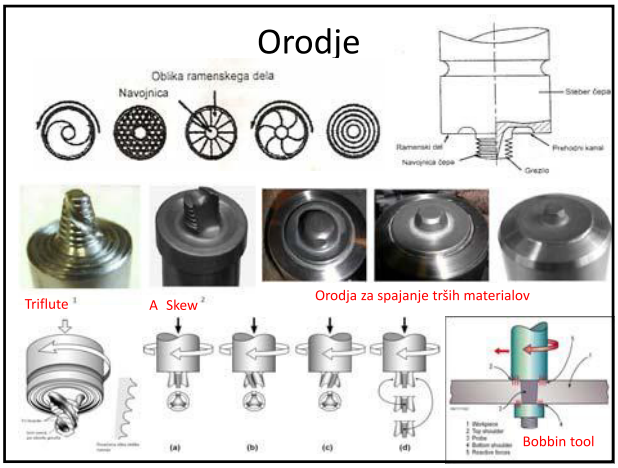

Taylored blanks

Spajamo lahko v vseh legah:

- vodoravno,
- navpično,
- nadglavno,
- orbitalno.



Orodje



Orodja za spajanje trših materialov

Izvedbe orodij

Orodje	Cilindrično	Whorl™	MX triflute™	Flared triflute™	A skew™	Re stir™
Shema						
Oblika trna	Cilindričen z navoji	Koničast z navoji	Navojni s tremi žlebiči	Trije žlebiči, na koncu razširjeni	Poševen, cilindričen z navoji	Koničast z navoji
Razmerje volumna trna proti volumnu cilindričnega trna	1	0,4	0,3	0,3	1	0,4
Možnost nasprotnega vrtenja	Ne	Ne	Ne	Ne	Ne	Da
Uporaba	Varjenje sočelnih zvarov, ni za prekrivne zvare	Varjenje sočelnih zvarov z manjšim navorom	Varjenje sočelnih zvarov z najmanjšim navorom	Varjenje kotnih zvarov pri manjši debelini zgornje plošče	Varjenje kotnih zvarov pri manjši debelini zgornje plošče	Ko je zaželjena minimalna asimetrija oblike zvara

Material orodja / Materials for tools

	AISI	Wr. Nr.	
ASP 30	M3:2 + Co	1.3244	hitrorezno jeklo
ASP 60		1.3241	hitrorezno jeklo
H11	H11	1.2343	orodno jeklo za delo v vročem
H13	H13	1.2344	orodno jeklo za delo v vročem
Ferro TiC SK			
MP 159			
Stellite 6B			
Ferro TiC HT 6A			
MAR M 246			
Mo TZM			
Rhenium			
Tungsten			
PCBN			

Materials for tools

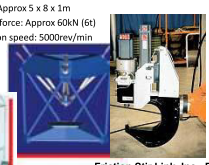
Material	Najvišja delovna temperatura [°C] Highest working temperature
H 13	540
Ferro TiC SK	590
MP 159	590
Stellite 6B	870
Ferro TiC HT 6A	980
MAR M 246	1040
Mo TZM	1315
Renij	1980
Volfram	1980

Stroji

- **ESAB SuperStir™** Sheet thickness: 1mm 25mm aluminium
- Work envelope: Approx 5 x 8 x 1m
- Maximum down force: Approx 60kN (6t)
- Maximum rotation speed: 5000rev/min

Crawford-Swift - High Force Multi Axis FSW machine
-over 130KW of spindle power
-12 programmable machine axes,
-a maximum down force of 15 tonnes and operates over an area of 6m x 3m.
-The machine has 3D welding capability
-an opposed welding head - a second welding head located directly beneath the upper head, which allows simultaneous, twin-sided welding to be performed. to weld materials up to 100mm thick in one pass

Neos Tricept



Hexapod

Friction Stir Link, Inc - RoboStir Robotic FSW Machine
-ABB 7600 robot.
- any position and follow complex 3D weld paths,
-working envelope of 5 metre diameter
- comprehensive data logging system to monitor and control the important FSW process parameter.
- FSSW.

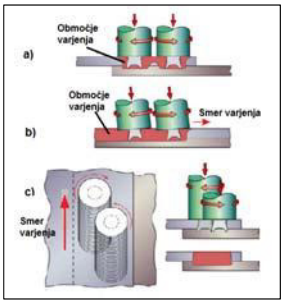
Izvedbe postopka

- **FSW (friction stir welding)** – varjenje z gnetenjem
- **FSShW (friction stir shoulder welding)** – varjenje z gnetenjem – z ramo
- **FSSW (friction stir spot welding)** – točkovno varjenje z gnetenjem (tool with retreating pin), s kroženjem, linearno
- **FSW z Bobbin tool** – spajanje brez podpore
- **FSDW (Friction stir diffusion bonding/welding)** za difuzijsko spajanje različnih materialov Al+Fe, Al+ Ti
- **Micro friction stir welding (µFSW)** – spajanje na mikro nivoju,
- **FSP (friction stir processing)** – spreminjanje mikrostrukture mehanskih lastnosti (superplastičnost)

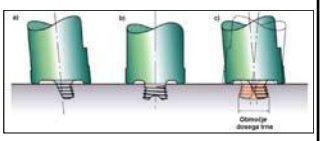
Patentirane izvedbe postopka

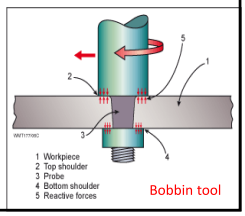
- Twin stir™ welding – FSW z dvema orodjema,
- Skew stir™ welding – FSW z nagibom orodja,
- Re stir™ welding – FSW s spreminjanjem smeri vrtenja orodja,
- Dual rotation FSW – FSW z neodvisno rotacijo,
- Pro stir™ welding – FSW predspajanje,
- Ras stir™ welding
- Bobbin tool stir welding – FSW z vretenastim ramenskim delom,
- Com stir™ welding
- EADS – Delta N tool – varjenje z mirujočo ramo

Twin stir



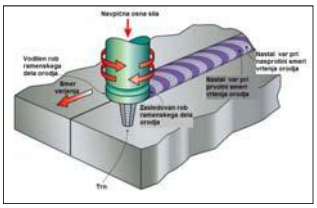
Skew stir



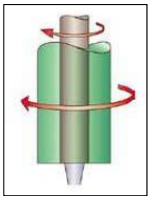


Bobbin tool

- Re stir



- Dual rotation



µFSW

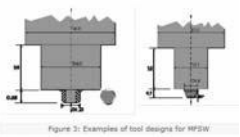


Figure 3: Examples of tool designs for MFSW

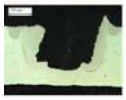


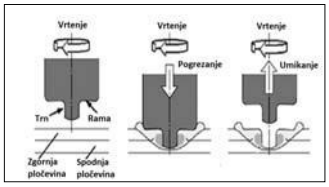
Figure 2: µFSW in progress through 300µm thick aluminium alloy sheet

http://www.twi.co.uk/technical-knowledge/published-papers/developments-in-micro-applications-of-friction-stir-welding/

Figure 5: Large bed µFSW machine at TWI with supplementary radiant heating delivered by fibre to the µFSW head

Figure 11: µFSW spot welding of dissimilar materials – aluminium connector to copper cable. Crimped only (right). Crimped and Spot Welded (left)

FSSW (friction stir spot welding, first application and patent – Mazda RX8 2003)



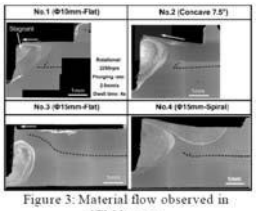
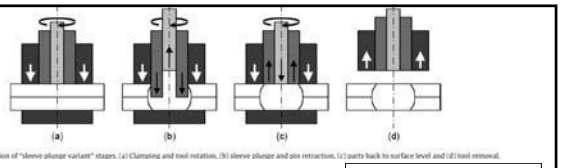
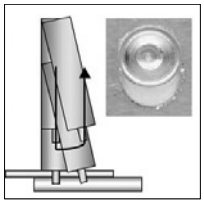


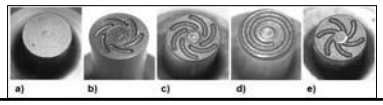
Figure 3: Material flow observed in SEM images.

- Welding parameters:
  - Tool rotation speed (hitrost vrtenja orodja)
  - Dwell time (čas zadrževanja orodja na mestu)
  - Plugne rate (hitrost pomikanja orodja v material)
  - Plunge depth (globina potopitve orodja v material)

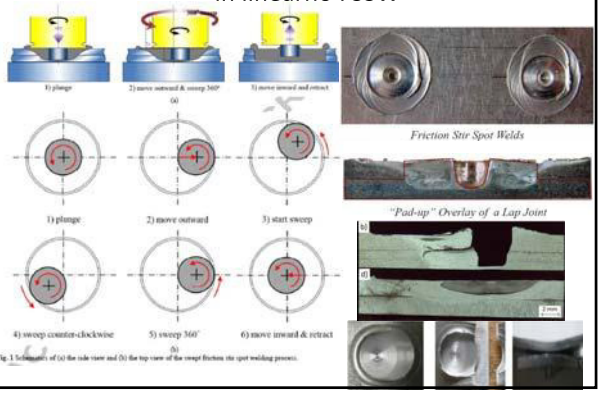


- FSSW welding with hole filling (dos Santos) Aerospace
- FSSW with oscilation
- FSSW with pinless tools tool examples





Swept FSSW z rotacijo orodja (MTI) in linearno FSSW

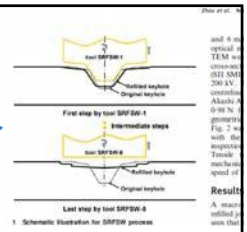


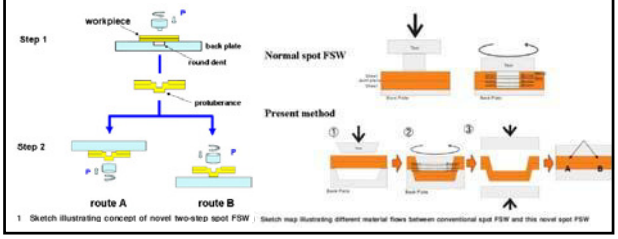
Friction Stir Spot Welds

"Pad-up" Overlay of a Lap Joint

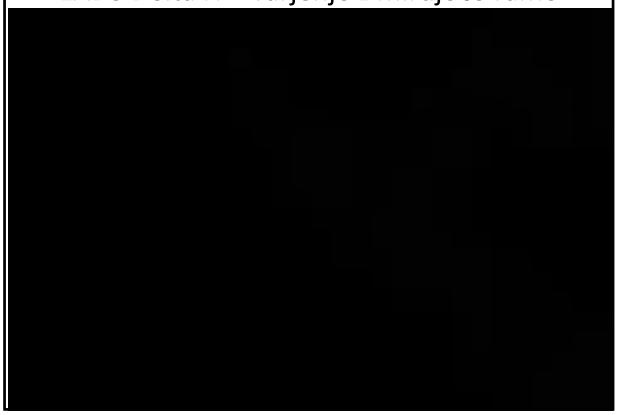
Polnjenje luknje pri FSSW

- Z dvema orodjema
- V dveh korakih z matrico





EADS Delta N – varjenje z mirujočo ramo



Patenti / licenčnina

- Licenčnina: odvisna od velikosti podjetja, ali podjetje deluje na več lokacijah,
- Letno cca. 35 000 – 50 000 EUR

TITLE: R198 - Improvements Relating To Friction Welding (Friction Stir Welding)

GRANTED PATENTS:

Australia	662 310	27 Nov. 1992 for 20 years
Canada	2 123 097	27 Nov. 1992 for 20 years
France	0 615 480	27 Nov. 1992 for 20 years
Germany	P 6920 5991.1	27 Nov. 1992 for 20 years
Great Britain	0 615 480	27 Nov. 1992 for 20 years
Hong Kong	HK 1006431	27 Nov. 1992 for 20 years
Japan	271 283 8	27 Nov. 1992 for 20 years
Singapore	9592176-3	27 Nov. 1992 for 20 years
Sweden	0 615 480	27 Nov. 1992 for 20 years
Switzerland	0 615 480	27 Nov. 1992 for 20 years
USA	5 460 317	27 Nov. 1992 for 20 years

TITLE: R227 - Friction Stir Welding

GRANTED PATENTS:

Australia	676 424	5 Jan. 1995 for 20 years
Belgium	0 752 926	5 Jan. 1995 for 20 years
Canada	2 182 719	5 Jan. 1995 for 20 years
China	ZL 95192193.2	5 Jan. 1995 for 20 years
Czech Republic	287 673	5 Jan. 1995 for 20 years
Denmark	0 752 926	5 Jan. 1995 for 20 years
Finland	109 886	5 Jan. 1995 for 20 years
France	0 752 926	5 Jan. 1995 for 20 years
Germany	0 752 926	5 Jan. 1995 for 20 years
Great Britain	0 752 926	5 Jan. 1995 for 20 years
Italy	0 752 926	5 Jan. 1995 for 20 years
Japan	279 223 3	5 Jan. 1995 for 20 years
Korea	0 219 003	5 Jan. 1995 for 20 years
Netherlands	0 752 926	5 Jan. 1995 for 20 years
Norway	314752	5 Jan. 1995 for 20 years
Poland	176 524	5 Jan. 1995 for 20 years
Portugal	0 752 926	5 Jan. 1995 for 20 years
Russia	2 126 738	5 Jan. 1995 for 20 years
Spain	0 752 926	5 Jan. 1995 for 20 years
Sweden	0 752 926	5 Jan. 1995 for 20 years
Switzerland	0 752 926	5 Jan. 1995 for 20 years
USA	5 813 592	29 Sept. 1998 for 17 years

Table 1. Chronology of Production Applications for FSW through 2004.

Year	Application	Company
1995	*Hollow heat exchangers	Marine Aluminum, Norway
1996	*Commercial shipbuilding	Marine Aluminum, Norway
1998	Delta II rockets	Boeing, US
1999	*Commercial shipbuilding	SAPA, Sweden
2000	*Automotive components	SAPA, Sweden
2000	Laser system housings	General Tool, US
2001	*Motor housings	Hydro Aluminum (formerly Marine Aluminum), Norway
2001	*Automotive components	Showa, Japan
2001	*Train bodies	Hitachi, Japan
2002	*Automotive components	Tower Automotive, US
2003	Aircraft structure	Eclipse, US
2003	*Commercial shipbuilding	Advanced Joining Technologies, US
2004	Space shuttle external tanks	Lockheed Martin, US
2004	Food trays	RIFTEC, Germany

*Denotes welding of extrusions

Table 2. Typical mechanical properties of friction stir welded aluminium specimens (numbers in brackets have been calculated from publications)

Material	0.2% Proof strength MPa	Tensile strength MPa	Elongation %	Welding factor UTS FSW /UTS Parent
6083-O Parent	148	298	23.5	N/A
6083-O FSWed	141	298	23.0	[1.00]
6083-H321 Parent	249	336	16.5	N/A
6083-H321 FSWed	153	301	22.5	0.91
6082-T6 Parent	286	301	10.4	N/A
6082-T6 FSWed	160	254	4.80	[0.83]
6082-T6 FSWed and aged	274	304	6.4	[1.00]
6082-T4 Parent	149	268	22.0	N/A
6082-T4 FSWed	138	244	18.8	[0.93]
6082-T4 FSWed and aged	265	310	9.9	[1.19]
7108-T79 Parent	295	370	14	N/A
7108-T79 FSWed	210	320	12	[0.86]
7108-T79 FSWed naturally aged	245	350	11	[0.95]

Uporaba tehnologije / Industrial Applications

Ladjedelništvo, pomorska industrija:

paneli za palube, stranice, nadstropja

ekstrudiran Al

paneli iz satovja, …

- **Shipbuilding and Marine Construction**
- The shipbuilding and marine industries are two of the first sectors that have adopted the process for commercial applications.
- The process is suitable for the following applications:
- Panels for decks, sides, bulkheads and floors
- Hulls and superstructures
- Helicopter landing platforms
- Marine and transport structures
- Masts and booms, e.g. for sailing boats
- Refrigeration plant

Železniška industrija / Railway Industry

paneli za pode, stranice in strope vlakov

vagoni za prevoz tovora

cisterne in kontejnerji

- High speed trains
- Rolling stock of railways, underground carriages, trams
- Railway tankers and goods wagons
- Container bodies

Vesoljsko – letalska industrija / Aerospace Industry

krila, rezervoarji za letala, kriogeni rezervoarji za gorivo vesoljskih plovil strukturne komponente, popravila slabih MIG varov, deli letal

- Wings, fuselages, empennages
- Cryogenic fuel tanks for space vehicles
- Aviation fuel tanks
- External throw away tanks for military aircraft
- Military and scientific rockets
- Repair of faulty MIG welds

Space Shuttle

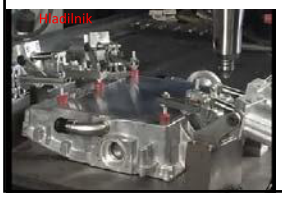
Ares I kupola (NASA)

Transport po kopnem / Land Transportation

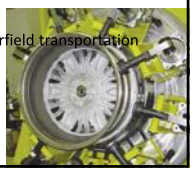
deli karoserije, hladilniki/grelniki, platišča

Mazda RX-8

- Engine and chassis cradles
- Wheel rims
- Attachments to hydroformed tubes
- Space frames, e.g. welding extruded tubes to cast nodes
- Truck bodies & tail lifts for lorries
- Mobile cranes
- Armour plate vehicles
- Fuel tankers
- Caravans
- Buses and airfield transportation vehicles



Hladilnik



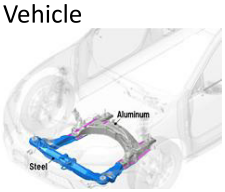
Platišča

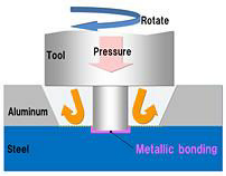
Honda Develops Weld Together Steel and Aluminum 1. Application to the Frame of a Mass production Vehicle

Hybrid Structured Front Subframe Achieves Both Weight Reduction and Increased Rigidity

TOKYO, Japan, September 6, 2012 Honda Motor Co., Ltd. today announced that it has newly developed a technology for the continuous welding of the dissimilar metals of steel and aluminum and applied it for the first time in the world to the subframe of a mass production vehicle, a key component of a vehicle body frame. Honda will adopt this technology first to the North American version of the all new 2013 Accord, which will go on sale in the United States on September 19, 2012, and will expand application sequentially to other models.

- Front subframe





The Tech Behind Apple's Impossibly Thin New iMacs

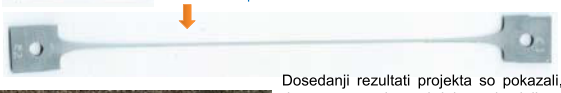
The new iMacs are just 5 mm thick for the entirety of the desktop's perimeter. To maintain that along seams where the front and back pieces meet, Apple used a process called friction stir welding (FSW)

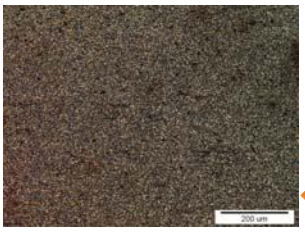
FSP – friction stir processing – grain refinement superplasticity of materials – superplastic forming

Zlitina Al 4.5Mg 0.3.5Sc 0.15Zr, Zlitina je bila obdelana po postopku trenja in mešanja (FSP)

Preizkušanec pred nateznim preizkusom

Preizkušanec po superplastičnem preoblikovanju z raztezkom 1900% brez porušitve





Dosedanji rezultati projekta so pokazali, da se s postopkom obdelave aluminijeve pločevine s postopkom trenja in mešanja (FSP) dosežejo bistveno boljše superplastične lastnosti kot s konvencionalnimi postopki. Z optimalnimi procesnimi in preoblikovalnimi parametri smo ob ustrezni zlitinski sestavi dosegli raztezke do 1900% brez porušitve materiala in to pri relativno velikih preoblikovalnih hitrostih.

Mikrostruktura zlitine po obdelavi s FSP s povprečno velikostjo kristalnih zrn 1 µm