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https://doi.org/10.4224/23002292

Trends in aluminum laser welding: Lightweighting applications

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14 Sept. 2017

CANWELD
EXPO & CONFERENCE 2017
METAL FABRICATING – WELDING – FINISHING

Outline

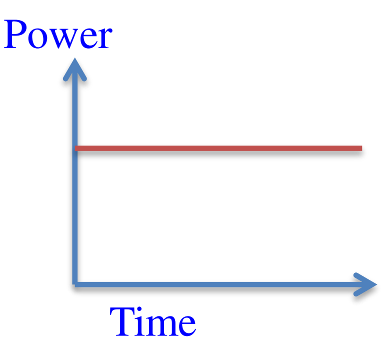
- Introduction
- Laser-cold wire welding of thick AA 6XXX aluminum alloys
  - **Single pass butt joint** **laser-cold wire** welding of **4.5 mm thick** AA 6XXX
  - **Gap bridging capability** of butt joint laser-cold wire welding method
  - **Multi-Pass** butt joint laser-cold wire welding of **6.5 mm thick** AA 6XXX
  - **Fillet lap joint** laser-cold wire welding of AA 6XXX
- **Laser oscillation** welding method
- **Pulse laser welding** of **non-weldable** **AA7075-T6**
- **Laser-remelt** method to improve **fatigue property of GMAW**
- Lap joint **laser welding of thin AA 5XXX** -backside **esthetism assessment**

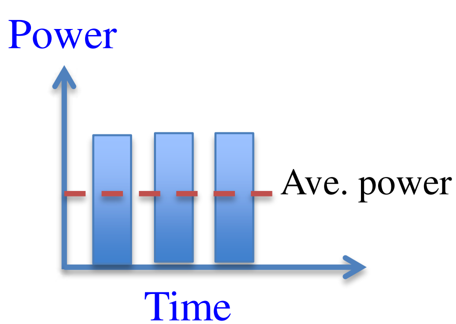
Introduction
Laser welding processes

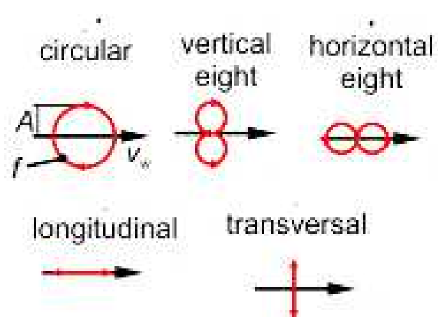
Laser welding processes

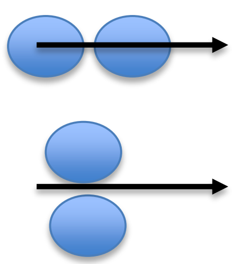
- Autogenous laser welding
- Laser cold/hot wire welding
- Hybrid Laser-arc welding

- Continous
- Pulse
- Oscillation
- Double spot







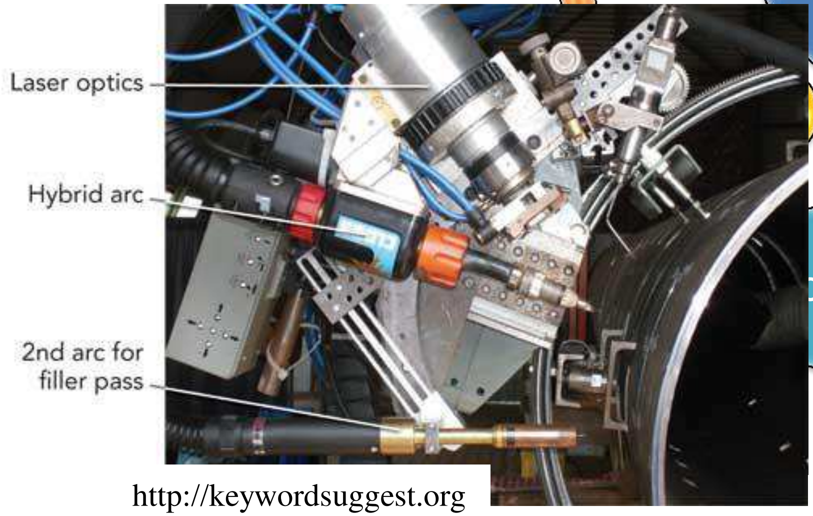


Introduction
Applications

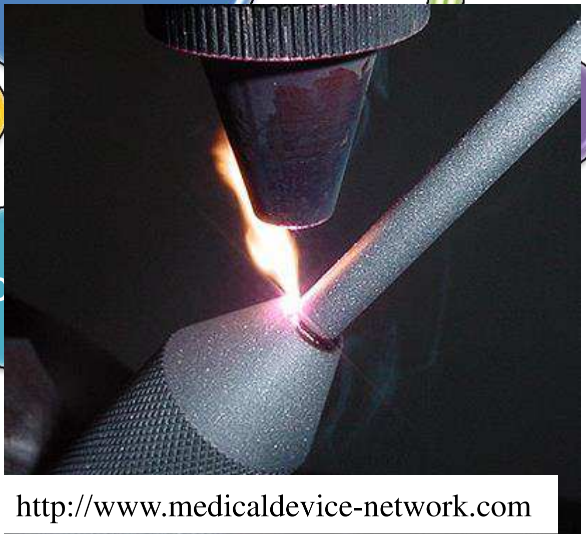
Volvo roof laser seam welding
http://www.industrial-lasers.com

Laser welded train wall panel
http://www.industrial-lasers.com

www.ilt.fraunhofer.de



http://keywordsuggest.org



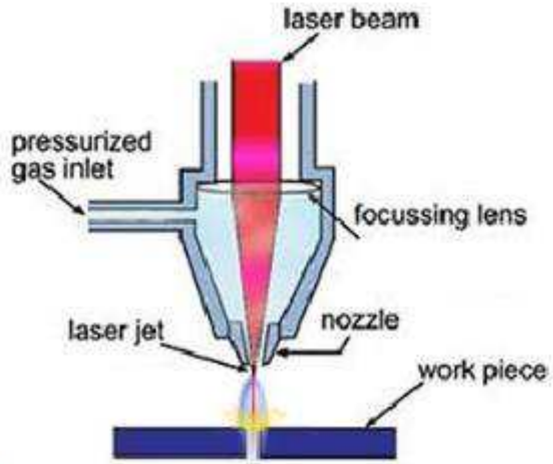
http://www.medicaldevice-network.com

http://www.energid.com

Introduction
Laser for welding

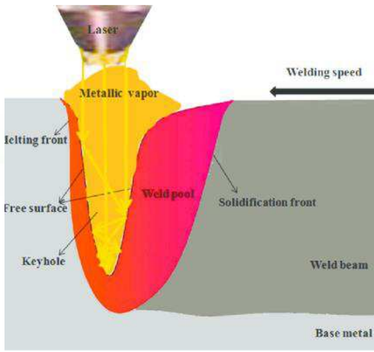
Main Advantages

- ➢ Higher welding speeds
- ➢ Deep penetration
- ➢ Low consumable consumptio
- ➢ Low heat input
- ➢ Reduced joint volumes
- ➢ Enhanced mechanical propert



Laser welding
http://www.ustudy.in/node/3830

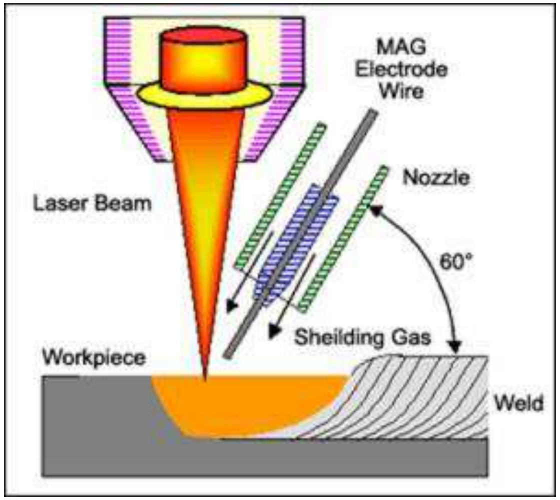
Conduction mode



Keyhole mode

Limitations

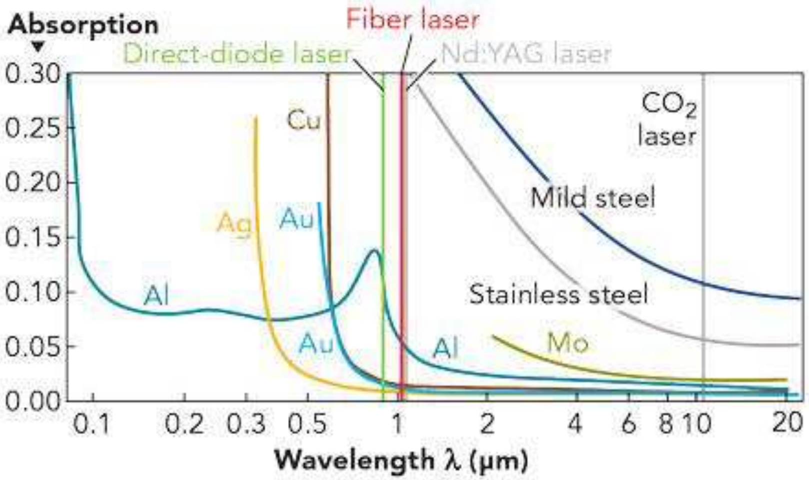
- Large number of parameters
- Additional safety measures
- Strict part fit-up
- Costly laser source (45k$CAD / kW)



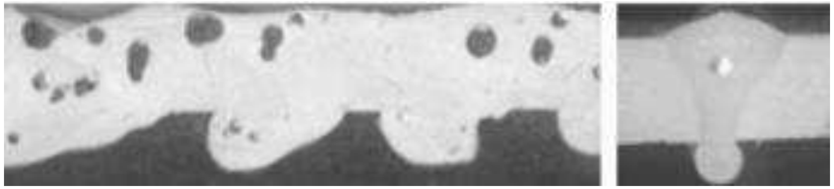
Laser-arc welding
IIW Annual Assembly, Osaka, Japan, 2004

Introduction
Laser welding problems on Al alloys

- Reflectivity by metal surface



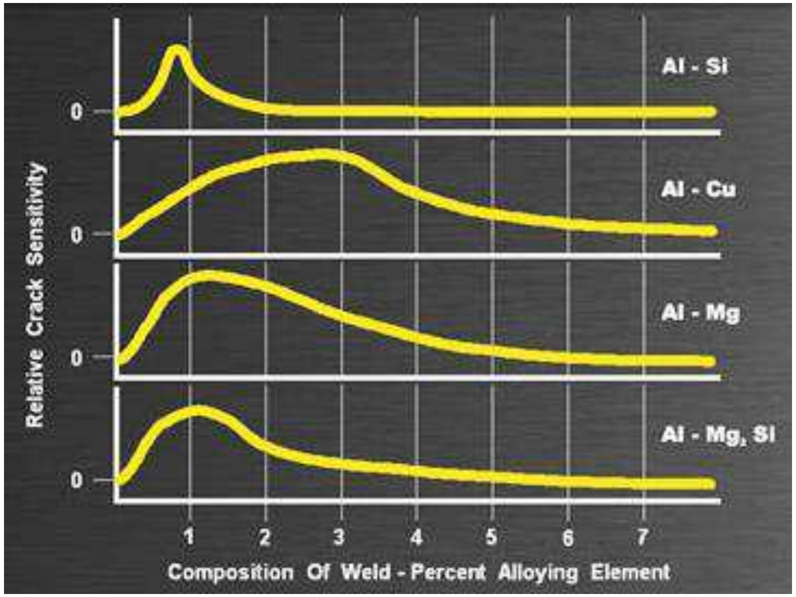
- Porosity and humping



Porosity in fibre laser weld 5XXX AL alloys

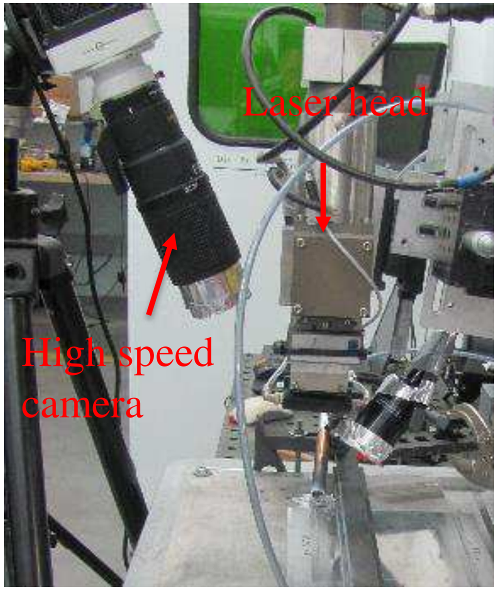
- Hot cracking

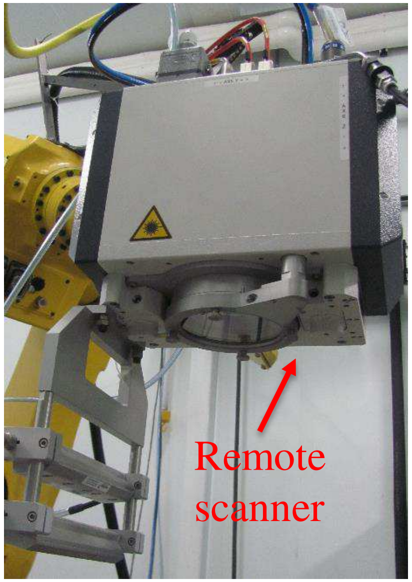
Hot cracking is an issue in autogenous mode and can be controlled to such extent with filler wire addition (Al-Mg; Al-Mg-Si)

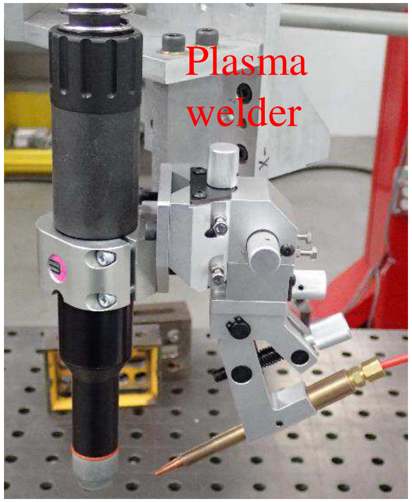


Equipment-Fusion welding

- TRUMPF TRUDISK 10 kW solid-state disk laser for welding
- Fronius & Lincoln GMAW
- Miller TIG Welder
- SBI International Plasma Arc welding







Laser welding of thick AA 6XXX Aluminium alloys

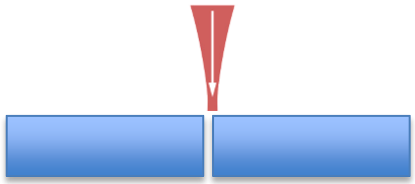
- ➢Butt joint laser cold wire welding
- ➢Gap bridging ability of laser-cold wire welding technique
- ➢Fillet lap joint laser-cold wire welding
- ➢Seam lap joint laser welding

Laser welding of thick Aluminium plates
Butt-joint design

Single pass butt joint welding of 4.5 mm thick AA6XXX Al plates

	speed m/min	WFR m/min	GAP mm	Power (kW)	Av. Power (kW)	Laser mode
1	3	5	0.7	10	6.7	pulse
2	3	5	0.7	6.5	-	CW

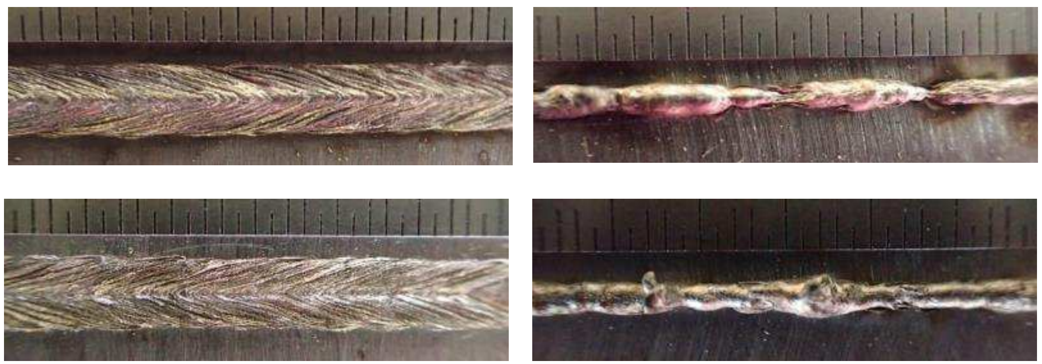
Laser beam



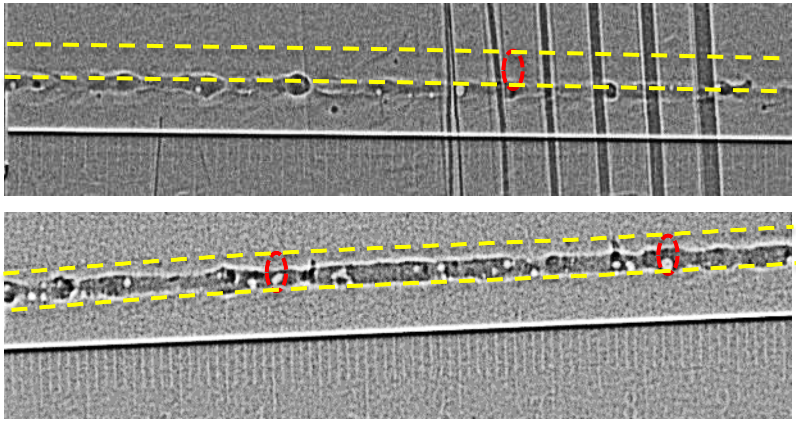
Top surface   Top surface

1

2



X-ray Photograph

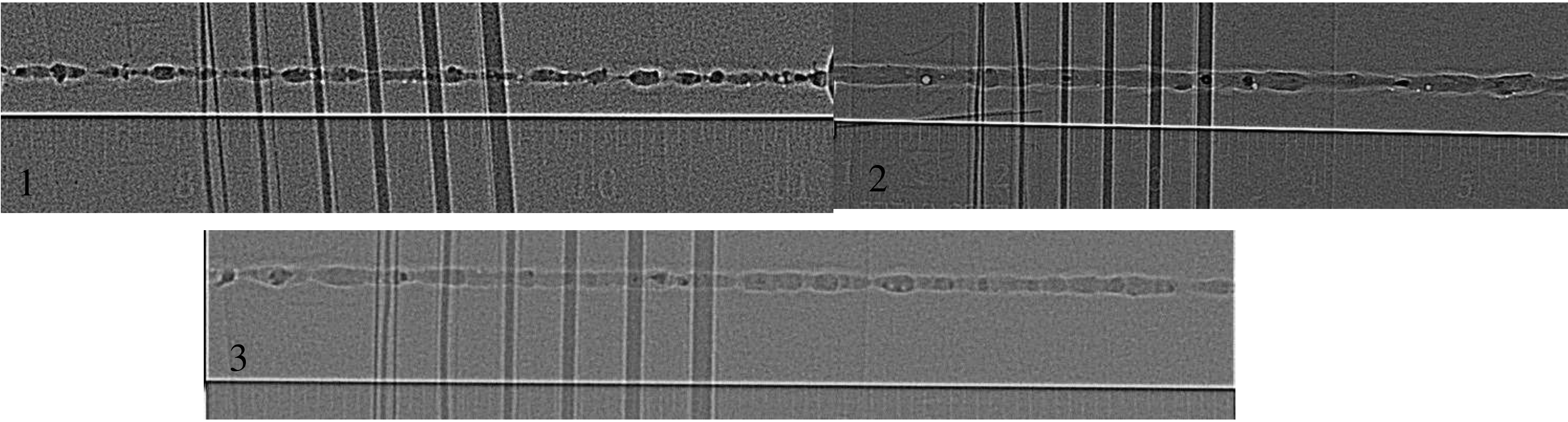


	Max. single porosity dimension	Max. cluster porosity dimension	Porosity area fraction
Trial #1	1 mm	1.2 mm	2.0%
Trial #2	1.7 mm	2.2 mm	5.6%
EN ISO 13919, Level B	$h \leq 0.3t$ (1.44 mm)	$h \leq 0.3t$ (1.44 mm)	$f \leq 3\%$
EN ISO 13919, Level C	$h \leq 0.4t$ (1.92 mm)	$h \leq 0.4t$ (1.92 mm)	$f \leq 6\%$

Laser welding of thick AA 6XXX Al plates
Butt-joint design

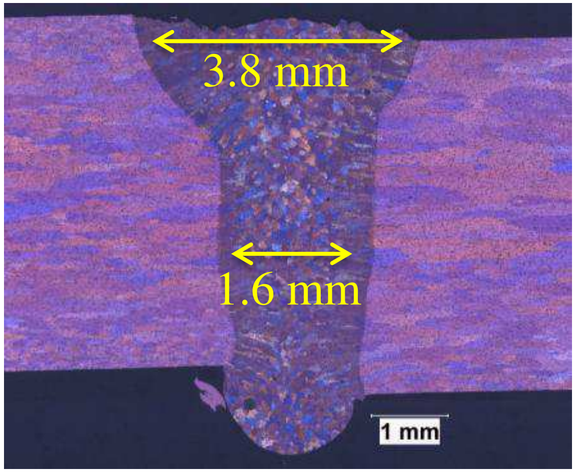
Gap bridge ability of laser-cold wire welding on 4.5 mm thick AA6XXX Al plates

n	power	Ave. Power	Speed m/min	WFR m/min	mode	Gap mm
1	10	6.5	3	3	pulse	0.3
2	10	7.7	2.75	6.5	pulse	1
3	8	-	4.5	6.5	CW	0.7

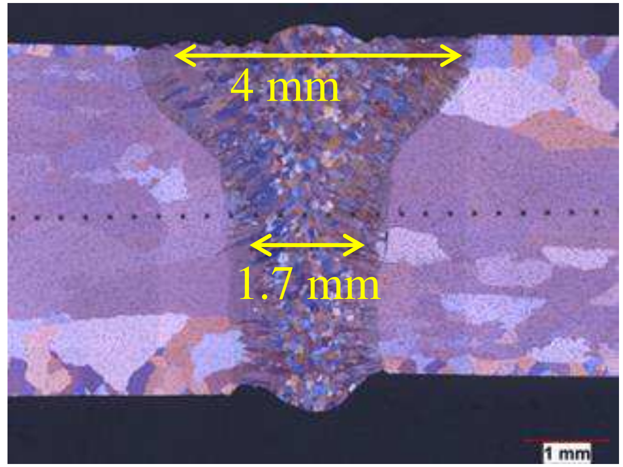


X-ray Photograph

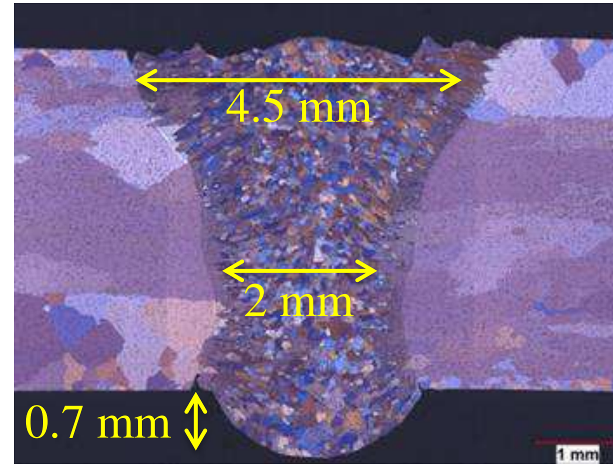
Laser welding of thick AA 6XXX Al plates macrostructure at different gap size and laser mode



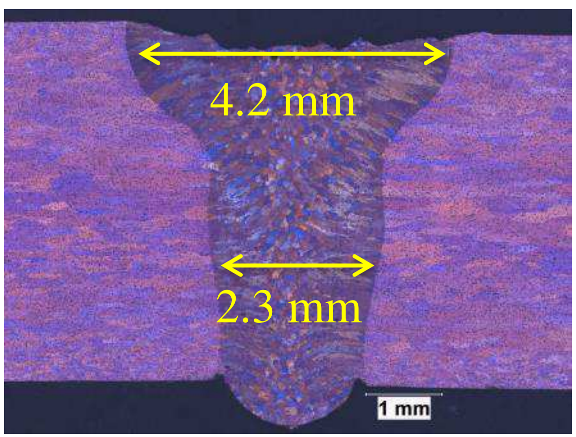
3 m/min, pulse, gap: 0.3 mm



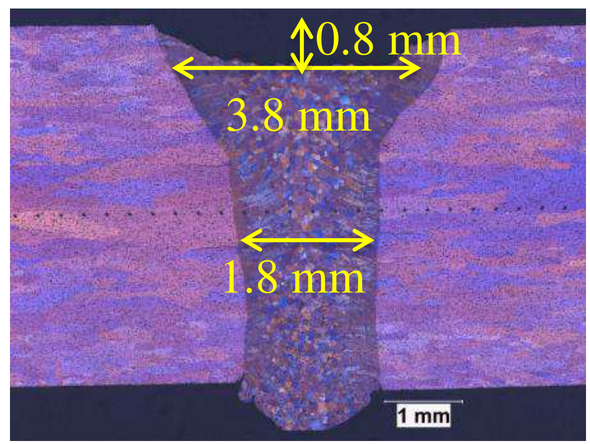
3 m/min, pulse, gap: 0.7 mm



2.75 m/min, pulse, gap: 1 mm



3 m/min, CW, gap: 0.7 mm

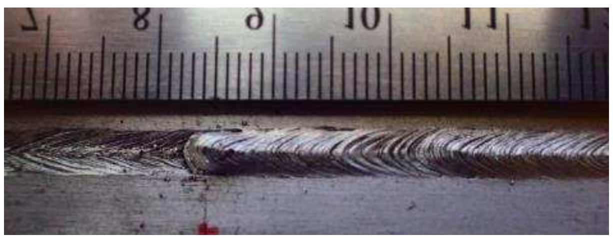


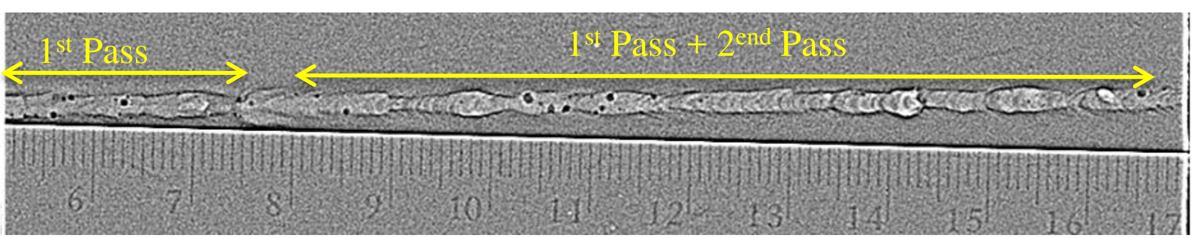
4.5 m/min, CW, gap: 0.7 mm

Laser welding of thick AA 6XXX Al plates
Two pass Butt-joint weld

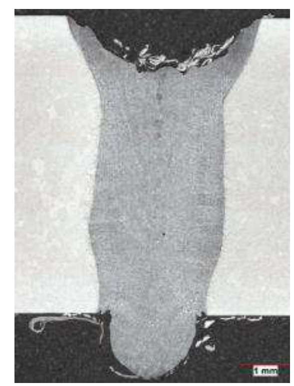
Two pass butt joint welding of 6.5 mm thick AA6XXX Al plates

	Welding speed m/min	Wire feed speed m/min	GAP mm	Power (kW)	Av. Power (kW)
pass1	4	3.5	0.5	9	-
pass2	3	4	-	4.5	6.48

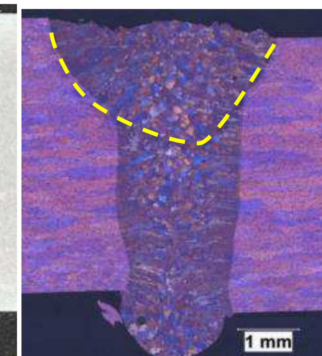




X-ray Photograph

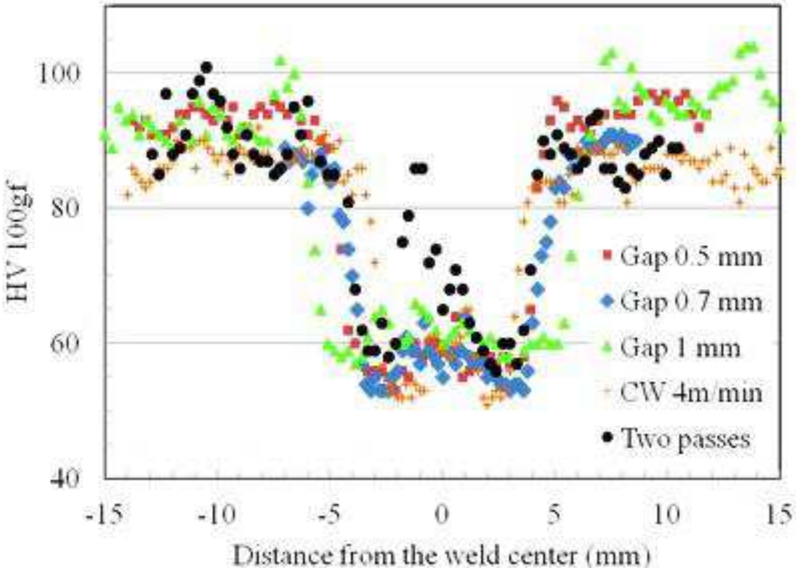


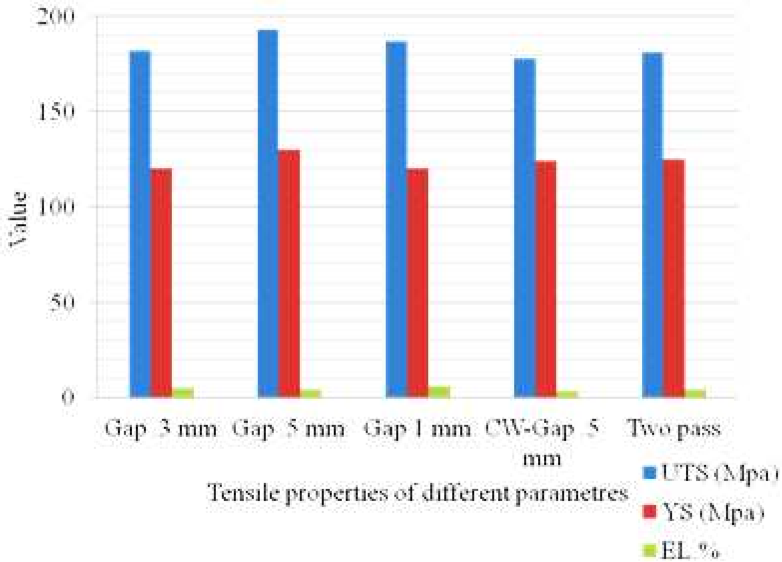
1st Pass



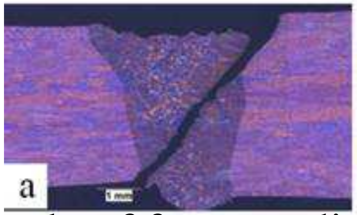
1st Pass + 2nd Pass

Butt-joint laser welding of thick AA 6005 AL alloys
Hardness & Tensile properties





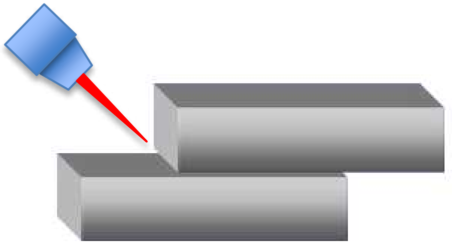
- The minimum hardness occurred in the FZ center (~34% softening compare to (BM).
- The harness increased gradually from FZ to HAZ and BM.
- The softening in FZ and HAZ is related to dissolution of smaller hardening precipitates and over-aging.
- The tensile properties of butt joint in pulse laser mode was slightly higher than CW laser mode
- The Tensile fracture start at FL, then the failure reach top surface, at the opposite direction, ending again to FL



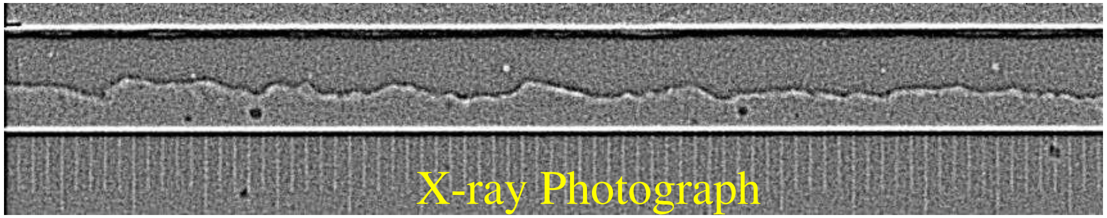
Example of fracture direction

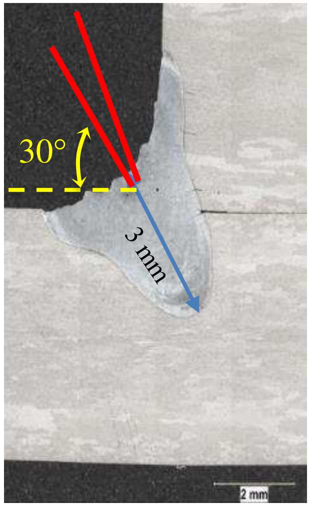
Laser-cold wire welding of thick AA6XXX AL Fillet lap joint

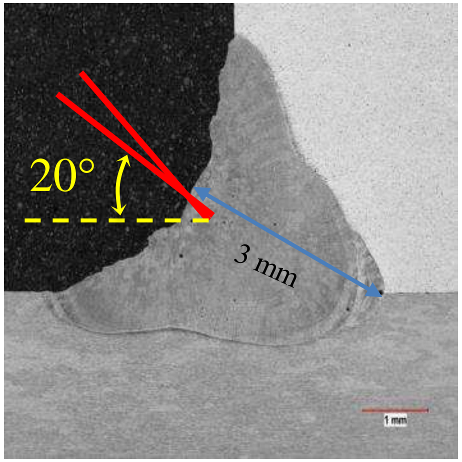
Effect of laser beam angle on weld bead geometry

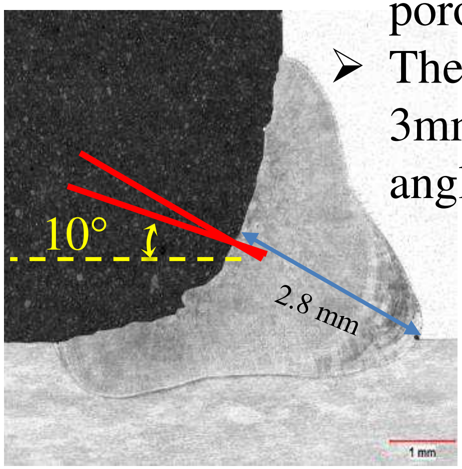


n	Power kW	Speed m/min	WFR m/min	Gap mm	Laser angle Deg.	Penetration mm
1-3	10	3	5	0	30, 20, 10	3, 3, 2.8









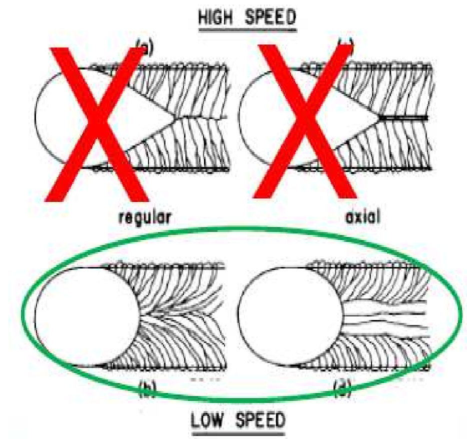
- Laser-cold wire welding of AA6XXX , without gap show no porosity.
- The maximum effective throat of 3mm was achieved at 20° laser angle

Pulse laser welding of 2 mm thick AA7075-T6

Conseil national de recherches Canada
National Research Council Canada

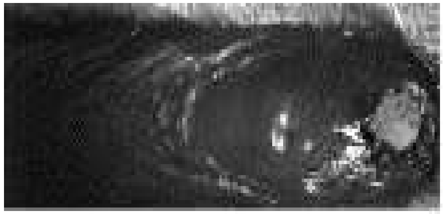
Pulse laser welding process development on AA7075-T6 2.0mm

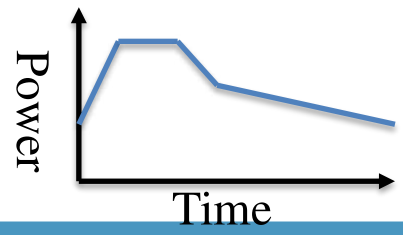
➢Molten pool as small as possible & round (limit alloying elements segregation & solidification shrinkage)

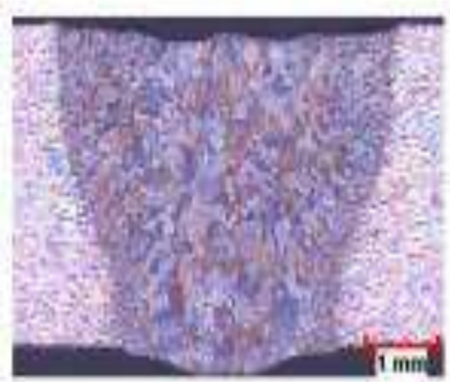


➢Welding energy as low as possible (limit alloying elements segregation

Ave. Power kW	Speed m/min	Tensile property
1.95	1	50% joint efficiency



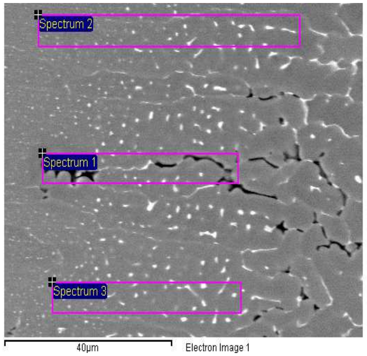




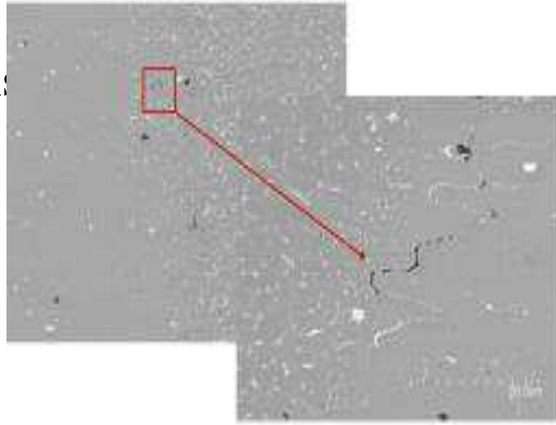
No Zn/Mg evaporation loss in fusion zone

Cold-wire laser welding process development on AA7075-T6 2.0mm

- The use of filler wire generally showed a better response toward hot cracking VS autogenous
- Welds at high speed of 4m/min show high amount of hot cracks & microvoid clusters (unsuitable at higher travel speed)



- Highest joint efficiency (62%) in tensile testing achieved using high Mg content filler wire of ER5556 (Al-4.5Mg)
- Microvoids at fusion line appeared, but less than the other conditions



Future work: use Sc modified filer metal

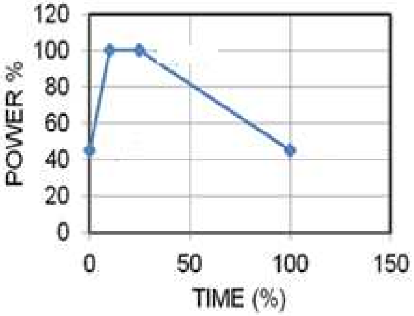
GMAW fatigue improvement using laser-remelting technique

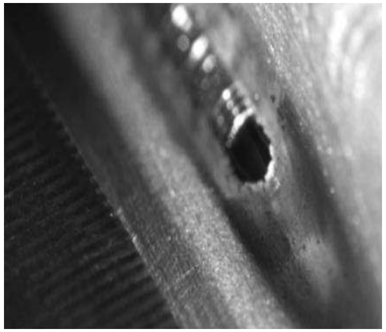
Conseil national de recherches Canada
National Research Council Canada
Canada

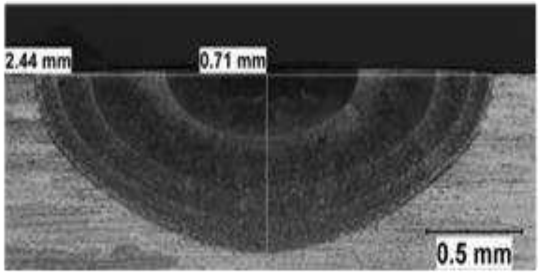
Laser-remelting Process development

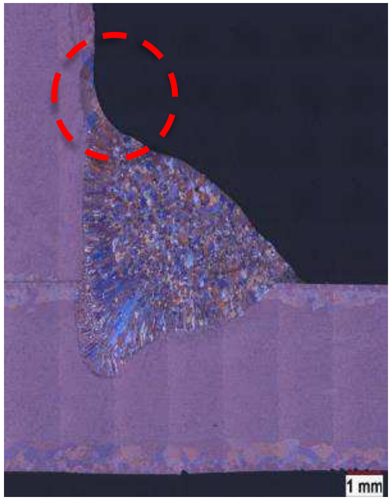
•Major task: Definition of the right pulse shape & parameters to improve weld toe geometry and avoid hot cracking

Power W	Speed m/min	Defocus mm	Av. Power W	Pulse Duration ms	mode
4730	0.8	+10	3500	20	conduction

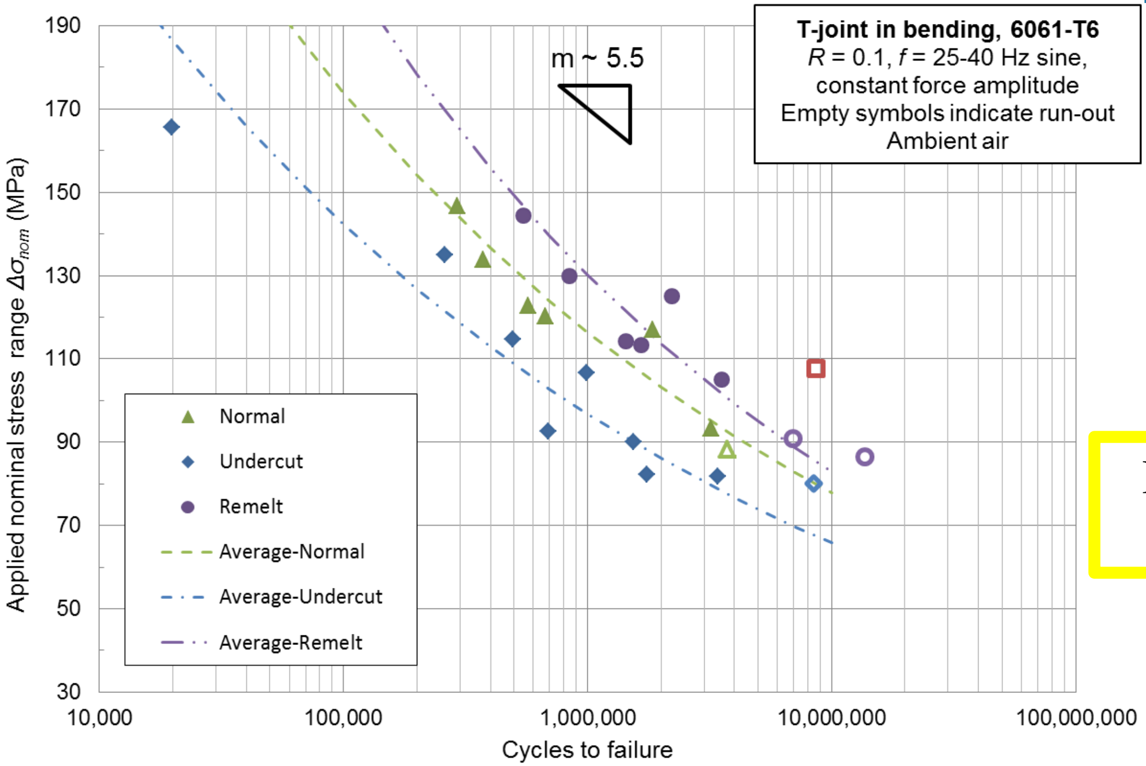


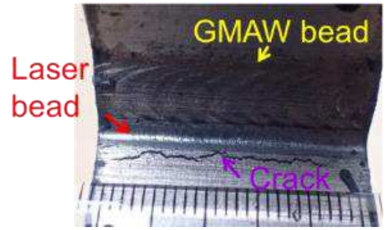






Fatigue test results- before and after laser-remelting





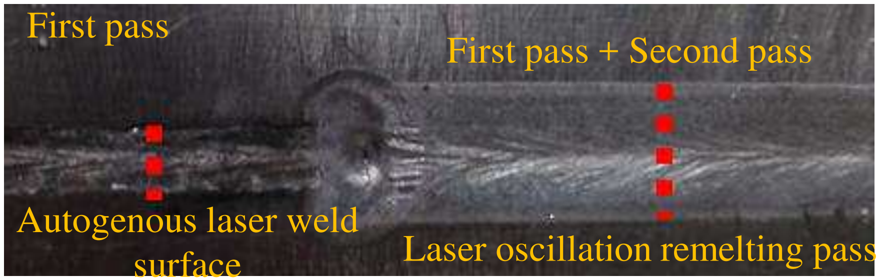
Laser speed 0.8 m/min

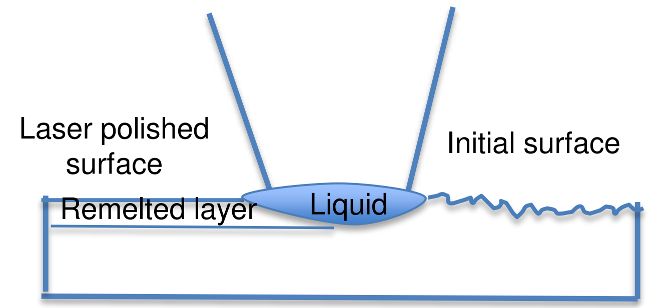
Future work: Using laser oscillation and double spot laser welding

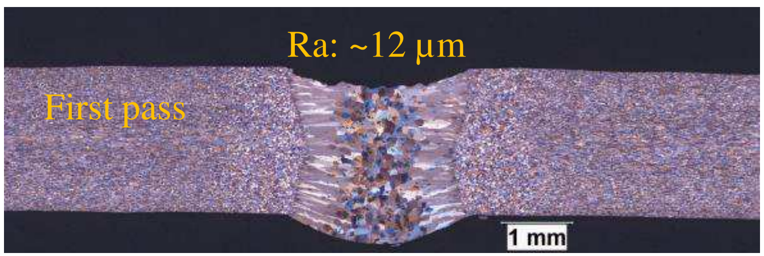
- Laser-remelting at **0.8 m/min**, on 6061-T6-GMAW T-joint, leads to **10-15% increase** in fatigue strength of **normal samples** at high fatigue cycle ($\geq 10^6$)
- This fatigue strength at 0.8 m/min laser speed on normal sample, compared to the as-welded GMAW with undercut, shows 30% increase in fatigue strength at high fatigue cycle

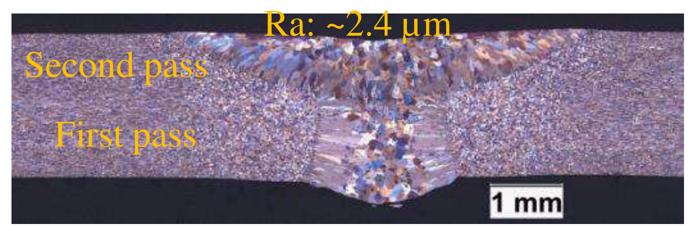
Laser oscillation technique

Laser oscillation technique to Polish as-welded surface









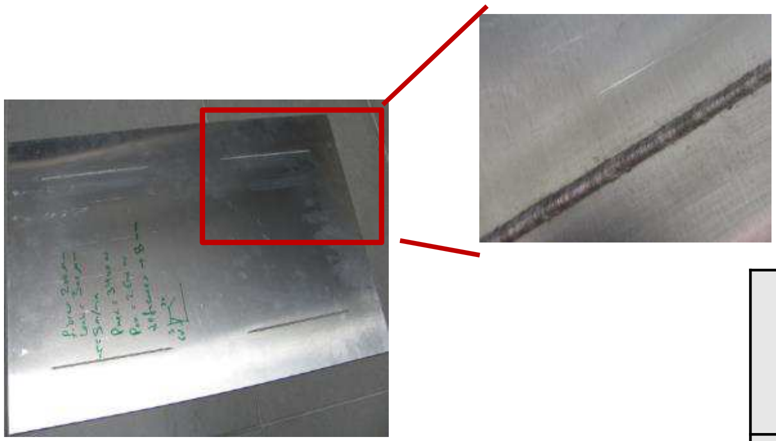
- Reducing the roughness of as welded surface by laser melting pass
- The polished surface area can increase 3 times using laser oscillation mode compare to pulse laser mode
- A thin surface layer is molten and the surface tension leads to a material flow from the peaks to the valleys. No material is removed but reallocated while molten, *Laser Polishing [*2017].

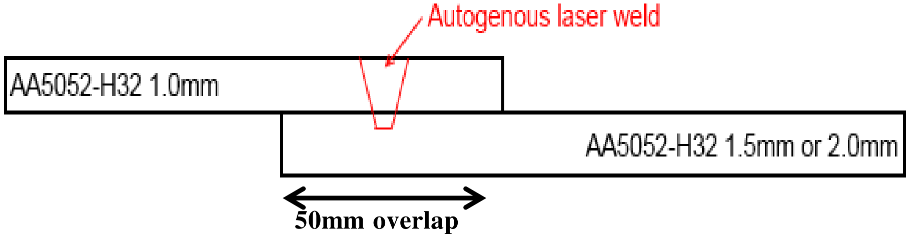
Other application:
Increase gap bridging in butt and lap joint laser welding , grain refinement in weld FZ

Autogenous laser welding-backside esthetism assessment

Autogenous laser welding- backside esthetism assessment

- **Stitch welding** of **1.0mm/2.0mm thick** AA5052-H32 Al alloy show **no distortion** in backside
- **Thinner bottom sheet was also suitable: 1.0mm/1.5mm thick**
- **Again,** interfacial failure is observed **but the backside finish esthetism is still kept !**
- **54% to 63% joint efficiency obtained for** 1.0mm / 2.0mm and 1.0mm / 1.5mm thick lap joints repectively.





Single lap shear strength assessment

Joint configuration	Width	Peak load	Peak stress	Joint efficiency
	mm	N	MPa	%
1.0mm / 2.0mm	25.6 +/- 0.2	3691 +/- 89	**144.4 +/- 3.2**	62.7%
1.0mm / 1.5mm	25.6 +/- 0.7	3176 +/- 159	**124.0 +/- 6.0**	53.9%

*AA5052-H32 base material UTS: 230MPa
Peak stress calculated on the upper sheet

Summary

Laser-cold wire welding of AA 6XXX alloy

- 4.7 mm and 6 mm thick 6XXX AL alloys were successfully welded using single pass and two pass laser-cold wire welding process
- Gap bridge ability of 1mm was achieved using laser-cold wire welding process for 4.7 mm thick plates and in butt joint design
- Porosity, underfill and excessive penetration were the most common welding defects.
- The welds passed the requirement criteria of ISO 13919-2 standard (level B) for defects.
- Hot cracking was not observed in butt joint laser cold wire under X-ray analysis and optic microscopy

Laser welding of 2mm thick AA7075-T6

- Pulse shape optimization has great effect on reducing the FZ hot rack of AA7075-T6
- The joint efficiency of 62% was achieved during laser welding of AA7075-T6 using of ER5556 filler

Summary

Fatigue improvement using laser-remelting technique

Laser remelting technique can improve fatigue property of GMAW up to 30% by optimizing the laser parameters such as pulse shape and speed

Laser oscillation technique

Laser oscillation welding was used as a second pass to improve surface roughness before paining. This also can improve mechanical properties of weld in structural application

Autogenous laser welding- backside esthetism assessment

Stitch welding of 1.0mm/2.0mm & **1.0mm/1.5mm** thick AA5052-H32 Al alloy was performed WITH **no distortion in backside**

Thank you!

Question?

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