ROWELDAL – Robust spot welding for next generation of light-weight vehicles

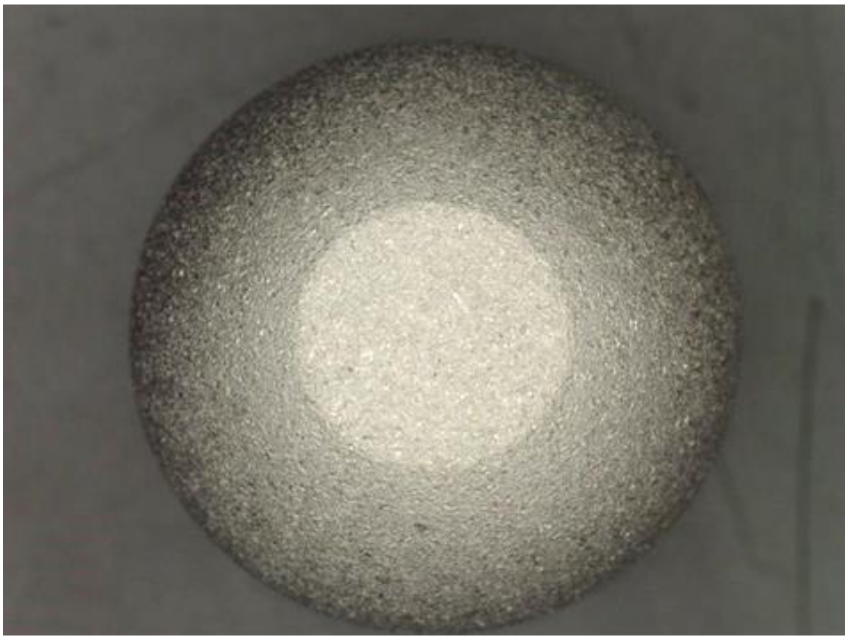

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Table of content

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1 Summary

Environmental demands are one of the great challenges for the automotive industry today. Due to these demands the use of lighter materials in the car body has increased the last years. Especially the use of aluminium alloys has increased rapidly during the last years.

The use of aluminium alloys in the automotive industry requires reliable and efficient joining techniques. One of the most commonly used joining techniques in the automotive industry today is RSW (resistance spot welding).

One big issue with RSW of aluminium alloys today is the heavily wear of the electrode tips. In order to maintain a high quality of the welds the electrodes needs to be dressed approximately every 10th spot. The dressing process takes approximately 2-3 seconds, plus the additional time it takes to move the robot to the formation station. This has to be considered as a great amount of time in an industry where every millisecond counts.

In this project a number of new materials for electrode caps are investigated in order to decrease or even cancel the need for tip dressing. The main idea is to add an inert coated surface between the cap material and the sheets in order to avoid alloying of the caps.

Another part of the project is to investigate the possibility to use laser ablation instead of the commonly used dressing with a cutting tool. In implementation of the laser ablation into the automotive industry is thought to both reduce the dressing time and the amount of wasted material, which would lead to an increased lifetime of the caps.

The results from the experiments show potential, although further tests needs to be done. There are indications that the coated caps can decrease the wear of the electrode. However, more experiments needs to be done in order to both reach a desired lifetime of the caps and maintain the weld quality. Also the experiments with the laser ablation indicate that this process can be useful. However, to ensure the quality of the cleaning process a better suited laser source needs to be evaluated.

2 Executive summary

The use of aluminium alloys in the automotive industry requires reliable and efficient joining techniques. One of the most commonly used joining techniques in the automotive industry today is RSW (resistance spot welding).

One big issue with RSW of aluminium alloys today is the heavily wear of the electrode tips. In order to maintain a high quality of the welds the electrodes needs to be dressed approximately every 10th spot. The dressing process takes approximately 2-3 seconds, plus the additional time it takes to move the robot to the formation station. This has to be considered as a great amount of time in an industry where every millisecond counts.

In this project a number of new materials for electrode caps are investigated in order to decrease or even cancel the need for tip dressing. The main idea is to add an inert coated surface between the cap material and the sheets in order to avoid alloying of the caps.

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The results from the experiments show potential, although further tests needs to be done. There are indications that the coated caps can decrease the wear of the electrode. However, more experiments needs to be done in order to both reach a desired lifetime of the caps and maintain the weld quality. Also the experiments with the laser ablation indicate that this process can be useful. However, to ensure the quality of the cleaning process a better suited laser source needs to be evaluated.

According to the project description the project has been fulfilled successfully. The two innovative ideas has been evaluated according to plan, but further tests needs to be done to have the possibility to promise successful results, although the pre study gives a good position for a continuing full project.

3 Background

3.1 Resistance spot welding of aluminium

In RSW (resistance spot welding) the heat is generated by Joule's law, (1.1). Most of the heat is generated in the interface between the sheets, due to the high contact resistance [1].

$$Q_J(t) = \int_0^t I^2(t)R(t)dt \qquad (1.1)$$

The total resistance of a 2-sheet stack-up can be expressed with, (1.2), where R1 and R5 is the contact resistance between electrode and sheet, R2 and R4 is the bulk resistance of the sheets, and R3 is the contact resistance between the sheets, Figure 1 [2].

$$R_{tot} = R_1 + R_2 + R_3 + R_4 + R_5 \qquad (1.2)$$

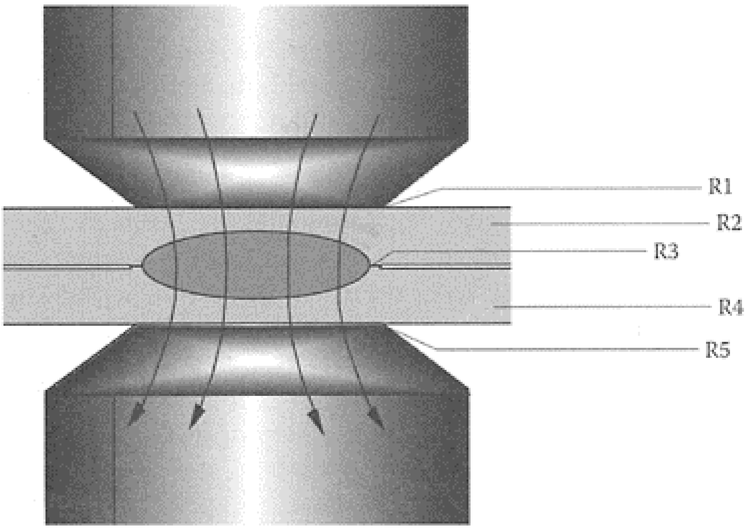

Figure 1. Resistance in RSW process, R1 and R5 are the contact resistance between electrode and sheet, R2 and R4 are the bulk resistance and R3 is the contact resistance between the sheets [3].

The contact resistance between the electrode and sheet, as well as between the sheets, is markedly larger than the bulk resistance in the early stage of the process. This is due to small irregularities in the surfaces, which concentrates the current to discrete areas of the interface. The high contact resistance implies that the weld is formed in the interface between the sheets. However, the combination of high temperature and pressure during welding can cause problems such as wear of the electrode tip. This is a common phenomenon in RSW of aluminium sheets due to the high contact resistance caused by insulating oxide layer on the aluminium surface. Controlling the contact resistance is thus very important in order to predict heat generation during welding and to prolong electrode life. According to the German Standard DVS 2929 a stable welding process can be achieved when the sheet-to-sheet contact resistance is kept between 20-50 µΩ. Contact resistance of different aluminium surface treatments has been measured by Z. Li et al. and large variations can be noticed, Figure 2. Worth to notice is that contact resistance values similar to what German standards specify is only achievable by special surface treatment of the aluminium sheets [4].

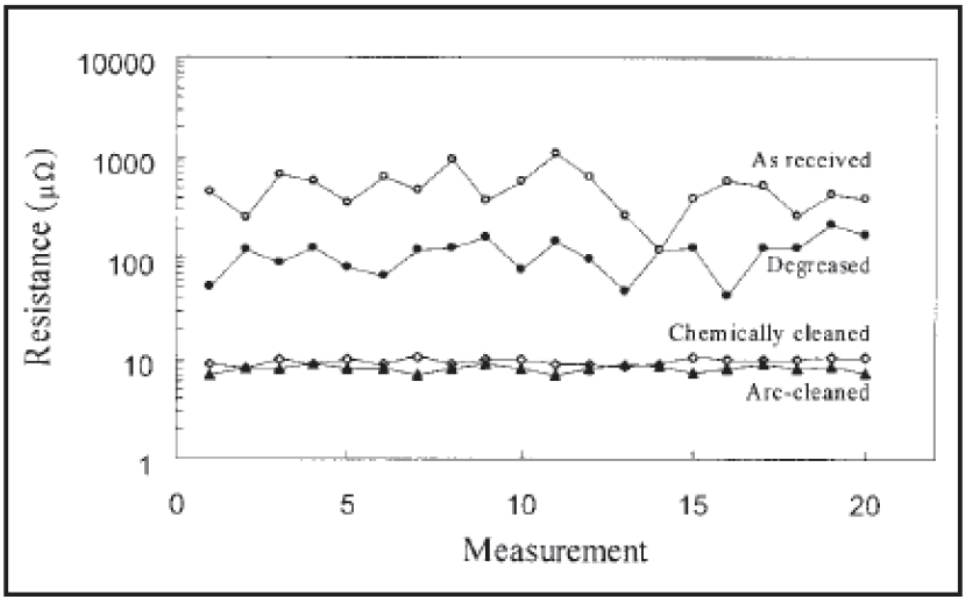

Figure 2. Variation in contact resistance of different aluminium surface treatments [4].

The contact resistance has a large influence on the lifetime of the electrode and the reliability of the weld results. Large variations in contact resistance can cause surface expulsion, which in turn decreases the electrode life. However, a controlled low contact resistance enables the possibility to weld a large number of consecutive spots without any loss of weld quality. Figure 3 shows how the electrode life decreases depending on the surface condition of the welded aluminium sheets [4].

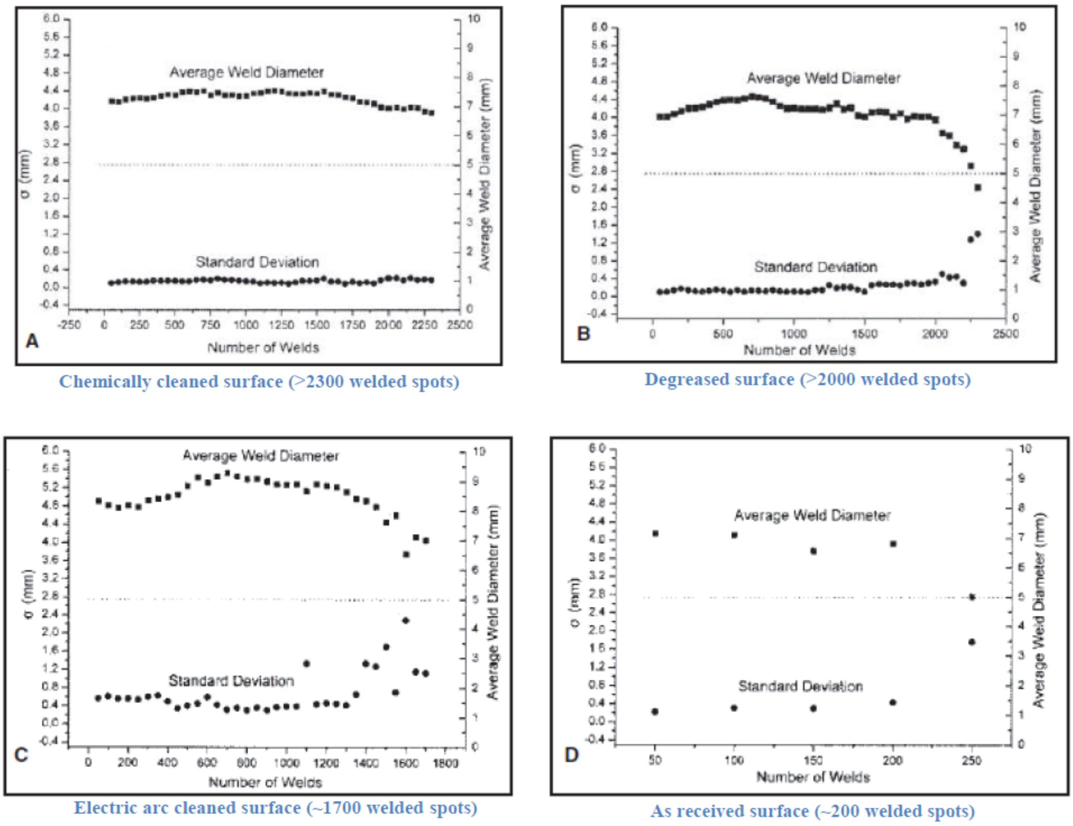

Figure 3. Electrode life depending on surface treatment [5].

The mechanism for electrode degradation during consecutive resistance spot welding has been described by I. LUM et.al. Figure 4 shows the three stages of electrode degradation. During RSW of aluminium the electrode force applied on the sheets causes the insulating oxide layer to crack. The current applied during welding is thus conducted through the cracks in the oxide layer, creating areas of much higher current densities than intended with the set welding parameters. The areas of extreme local current density put a lot of stress on the electrodes and thus jeopardize the integrity of the electrode surface. The areas of high current density cause melted aluminium to reach the electrode surface which initiates a type of chemical degradation of the electrode surface. Melted aluminium together with copper forms brittle intermetallic phases on the electrode surface which during consecutive welding results in material transfer from the electrode surface to the aluminium sheets and eventually the formation of surface pits on the electrode. The Al-Cu intermetallic phases also contribute to an increased contact resistance between electrode and aluminium sheet, resulting in increased heat generation during welding. Continued welding causes the surface pits to grow and eventually form larger cavities. This type of pit formation and cavitation of the electrode surface strongly contributes to the high degradation rate of electrodes during RSW of aluminium.

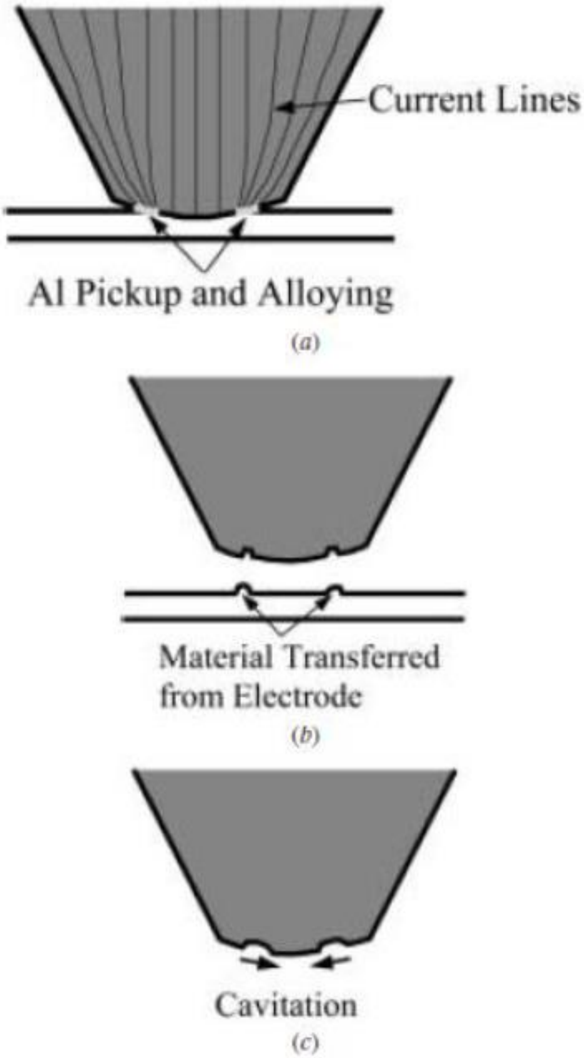

Figure 4. Schematic picture of the electrode degradation in RSW of aluminium [6].

A comparison between a newly dressed electrode tip and an electrode tip after 125 welds can be seen in Figure 5.

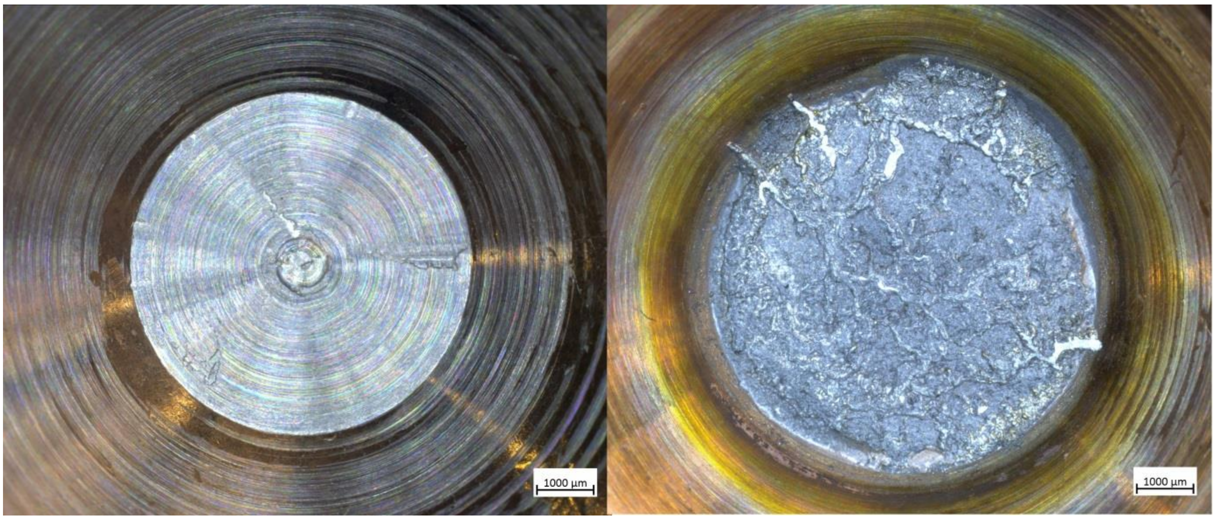

Figure 5. Comparison of newly dressed cap and cap used for 500 spots.

3.2 Alternative materials for electrode caps

A number of potential solutions to extend the lifetime of the electrodes for RSW of aluminium have been reported in the research report “Resistance spot welding for light weight design”, published by Swerea KIMAB in 2012 [4]. However, all these solutions have their own limitations, and it is therefore interesting to study other applications where electrodes are used to electrically contact aluminum.

Besides spot welding of aluminum there is at least two other applications where electrodes are used to electrically contact aluminum; Hall-Heroult cells for primary aluminum smelting and electrodes to contact aluminum coated high power semiconductors, e.g. thyristors and diodes.
For Hall-Heroult cells a recent development has been to use titanium diboride (TiB_2) as cathode since TiB_2 has chemical inertness and good electrical conductivity. TiB_2 is also used for crucibles handling molten aluminum [7]. Moreover, Cheng Luo et.al [8, 9] have studied spot welding of zinc coated steel sheets by using TiB_2 and TiB_2–TiC composite-coated electrodes. However, it has not yet been implemented in production.

The main requirement of electrodes to contact aluminum coated high power semiconductors, e.g. thyristors and diodes, is a low and stable contact resistance. The challenge is that the electrodes are subjected to sliding due to thermal mismatch between the electrodes and the semiconductor and lubrication cannot be used, which for most materials will result in fretting corrosion and catastrophic failure. However, there are some few coatings that can be used to contact aluminum coated semiconductors, e.g. rhodium and ruthenium. Rhodium can be electroplated and has high hardness, 800 – 1000 HV [10]. Furthermore, rhodium coated electrodes gives a unique low contact resistance in contact with aluminum, probably due to a combination of high hardness, very low adhesion to aluminum and a very thin oxide film. Rhodium coated copper-alloy electrodes have also been proposed and patented for spot welding of niobium sheets in order to reduce sticking [11].

Based on the above experience with TiB_2 and rhodium coated electrodes to contact aluminium it was decided to study TiB_2 and rhodium coated electrodes for spot welding of aluminium. The purpose with coated caps is to achieve “infinite” life length without dressing, and therefore it is important that the coating will not detach from the electrode. A hard coating may detach if the substrate is deformed during operation, or if the stress caused by thermal expansion mismatch between the coating and the substrate is too large. Therefore, in order to restrict plastic deformation of the substrate and to reduce the stress caused by thermal expansion mismatch between the coating and the substrate, solid molybdenum caps or copper-alloy caps with molybdenum insert were used in this study.

3.3 Laser ablation

Another part of this project was to evaluate the possibility to use laser ablation to clean the electrode surface instead of the more commonly used formation tool. The use of laser ablation would both speed up the cleaning process and decrease the amount of wasted material. The formation method which is used today cuts approximately 0,1 mm of the electrode tip and the time consumed for this process is in the range of 2-3 seconds, plus the additional time to move the robot to the formation station. This time could be heavily reduced with the use of optimal laser power and frequency of the laser pulses.

There are several laser based techniques to process metals. However, none of the commonly used techniques do exactly what is desired in this project, which is to ablate a relatively large part of material off a surface. Strong continuous wave (CW) lasers are used for cutting metal by melting a very small point. However, that does not lead to effective ablation. The more readily available ablation systems are aimed for cutting micro structures and polishing off oxides or organic surface contaminants [12, 13]. Laser cleaning of caps requires, in a controlled way, the possibility to remove a surface layer, which is indeed possible to do with lasers. One advantage with using lasers is that we can simultaneously analyze the surface material in order not to ablate longer than necessary.

The important laser-parameters are:

- wavelength
- pulse-length
- power (or pulse-energy)
- repetition rate (number of laser-pulses per second)
- a robust and easy to use laser system

Apart from more effective lasers it is also possible to use compressed gas in combination with the laser irradiation in order to enhance the efficiency of ablation. That however would require a more impractical set-up with the gas-nozzle located only ca 2 mm away from the electrode that is cleaned [14, 15].

Light of short wavelength can lead to a more effective ablation for several reasons:

- It is more likely to excite the metal over the band-gap which increases the chance of breaking molecular bonds [14].
- Longer wavelengths are to a larger extent absorbed in the formed plasma, which leads to screening and lower efficiency of ablation. In LIBS applications that is a good thing since it leads to more stable plasma. However, it is not favorable for the ablation process.
- Light of short wavelengths penetrate deeper into the material, which causes the laser energy to deposit in a more concentrated area which is positive for ablation [15].

The effect of pulse-length (temporal) is more difficult to predict. Short pulses dump the energy in the material faster than the lattice vibration of the metal which means that there is much less heat transfer. Instead the removal is more characterized by Coulomb-explosion and breaking of chemical bonds. It is clear that ultrafast lasers (ps or shorter) forms a cleaner ablation crater with less melt. However, it is unclear whether actually more material is removed or not [15, 16].

Repetition rate, one way of overcoming screening of the laser light by the plasma is to lower the energy just below the threshold for plasma-formation and instead increase the repetition rate. Each pulse deforms the surface which successively enhances the efficiency of ablation [17, 18, 19]. Even for laser-pulses with same pulse-energy a small time between each shot (i.e. high repetition rate) leads to higher ablation efficiency [20].

4 Method

4.1 Alternative materials for electrode caps

The following caps were evaluated in this project:

- Solid Mo-caps – TiB_2-coated (PVD coated)
- Solid Mo-caps – uncoated

- Cu-caps with Mo-tip
- Cu-caps with W-tip Cu-caps with Mo-tip – Rh-coated (electroplated)
- Solid Mo-caps – Rh-coated (electroplated)

The Cu-caps with Mo-tip or W-tip were commercial back-cast electrodes aimed for resistance welding. The chemical composition and the thickness of the coating layers of the rhodium-coated solid molybdenum-caps and the rhodium-coated copper-caps with molybdenum insert are presented in Table 1 and Table 2. The thickness of the TiB_2 coating was 1 µm.

Table 1. Chemical composition and thickness of coating layers for rhodium-coated solid molybdenum-caps.

Cap material	TZM (Mo + 0,5% Ti + 0,08 % Zr + 0,01-0,4 % C)
Coating layer 1	Nickel plate – 1,25 µm
Coating layer 2	Gold strike - 0,25 µm
Coating layer 3	Rhodium plate - 1 µm

Table 2. Chemical composition and thickness of coating layers for rhodium-coated cupper-caps with molybdenum tip.

Cap material	CuCrZr-alloys – A2/2
Tip material	TZM (Mo + 0,5% Ti + 0,08 % Zr + 0,01-0,4 % C)
Coating layer 1	Nickel plate – 1,25 µm
Coating layer 2	Gold strike - 0,25 µm
Coating layer 3	Rhodium plate - 1 µm

The geometry of all caps was according to standard (SS-IS 5821); B caps with an outer diameter of 16 mm, the tip diameter was 6 mm and the face radius was 40 mm. All caps that were intended to be coated were mirror polished prior deposition.

The first part of the experiments was to perform a reference tests with the commonly used A2/2 Cu-caps. 500 spots were welded without formation of the caps. Welding was done in AA6014 (AC170-PX from Novelis) with a thickness of 1.0 mm and as-received surface condition. Criteria in nugget size were 4.5 mm according to general standards, but the aim in this study was 5.0 mm to have a better margin. Expulsion was noticed and the nugget size was measure for every third spot. The result from this test is presented in chapter 6.1. The parameters for the experiments are presented in Table 3.

Table 3. Process parameters for lifetime test with Cu A2/2-caps.

Force [kN]	Squeeze Time [ms]	Current [kA]	Weld Time [ms]	Hold Time [ms]
2,5	700	25	120	500

The same tests were planned to be done with all the new developed caps in order to compare them to the Cu-caps. However, because of reasons further explained later in this report, these tests were not completed.

4.2 Laser ablation

To compare the laser ablation to the common formation process two parallel experiments were performed. The main idea with these experiments was to compare both the quality of the welds and the geometrical changes caused by the formation and the ablation. The tests were performed by welding 100 spots with two pairs of caps. After every tenth spot the height and contact area of the caps were measured, then the caps were dressed, one pair with formation tool and the other with laser ablation, and then measured again. The measurement of the contact area and the height were done with measuring tools in the software ZEN Core and an AXIO Zoom.V16 microscope. The change in height of the caps was measured by making a small mark on the side of the cap, as shown in Figure 6. The process parameters were the same as in the lifetime test, presented in Table 3.

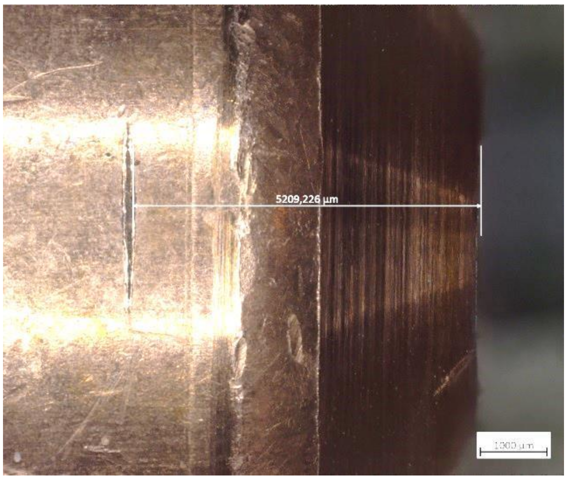

Figure 6. Illustration of how the height of the caps was measured.

Two different cleaning procedures where developed: a spinning type, Figure 7, and a row-wised type. Both methods involved a high intensity laser and a robot for moving the target. The laser used in the experiments was a Quantel Big Sky 100 mJ 20Hz and an industrial robot IRB 2600 from ABB. In order to easily change sample while still having a controlled setup an in-house developed holder was constructed, Figure 8 . The laser beam was guided through a lens that would focus and transform it into a narrow line, which gives a more intense ablation.

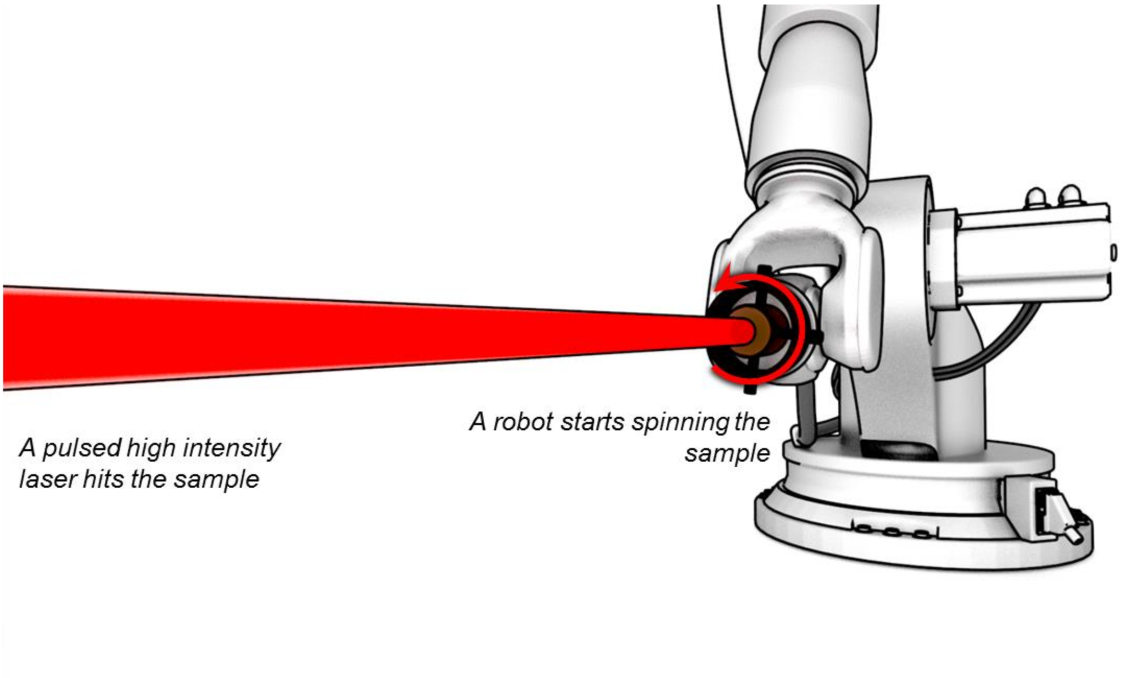

Figure 7. Schematic figure illustrating one of the cleaning procedures

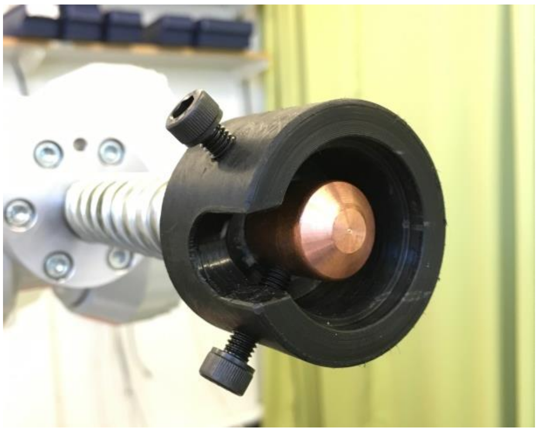

Figure 8. A specialized holder for the caps was developed in order to easily move the target

The two moving procedures were also further developed by implementing a spectral analysis in order to facilitate an automated technique where only the contaminants were ablated off, e.g. only copper left in comparison to aluminum present.

The test was not completed since the laser ablation did not clean the contact area good enough. This is further explained in the results section.

5 Aim

The purpose of this project was to enable large-scale robust spot welding of aluminum with existing infrastructure through innovative solutions for electrode cleaning, and solutions for reduced metallurgical interaction between electrodes and aluminum sheets. The developed solutions are targeted to, in difference to state-of-the-art solutions, be implemented in existing infrastructure and shall not affect productivity negatively. They should be possible to implement in all the positions in the factory where aluminum might be welded.
The concept study within this project has had two different approaches to achieve the goal with a robust, highly productive spot welding of aluminum:

- Applying laser ablation on the electrode surface to minimize the need for tip dressing the electrode. Laser ablation is possible to use on-line which does not interfere with productivity similar to other solutions in the literature.
- Applying a layer on the electrode surface with features to prevent sticking between the electrodes and metallurgical interaction between aluminum and copper. In this case the idea is to evaluate Rhodium as a coating. Rhodium has been used in applications in the electronics industry to prevent local welding in sliding contact between Al and Ni.

6 Results

6.1 Alternative materials for electrode caps

The result from the lifetime test with the Cu-caps is presented in Figure 9, with nugget size as function of number of welds. The first spatter occurred at the twenty-third spot.

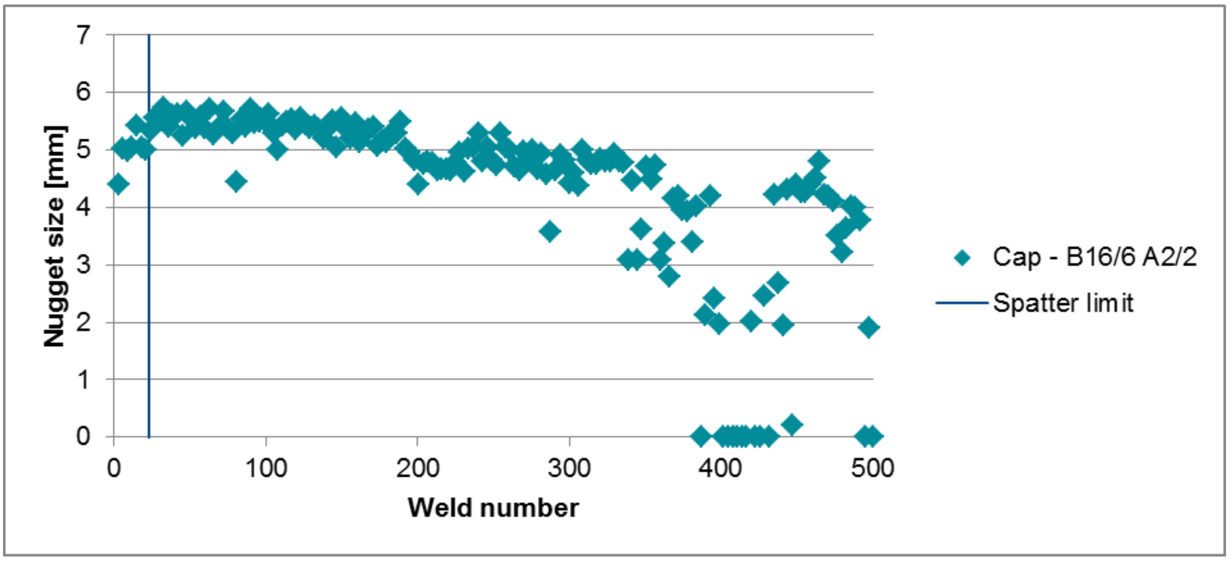

Figure 9. Result from lifetime test with Cu-caps.

The continuous wear of the electrode from the first spot to spot number 300 is illustrated in Figure 10.

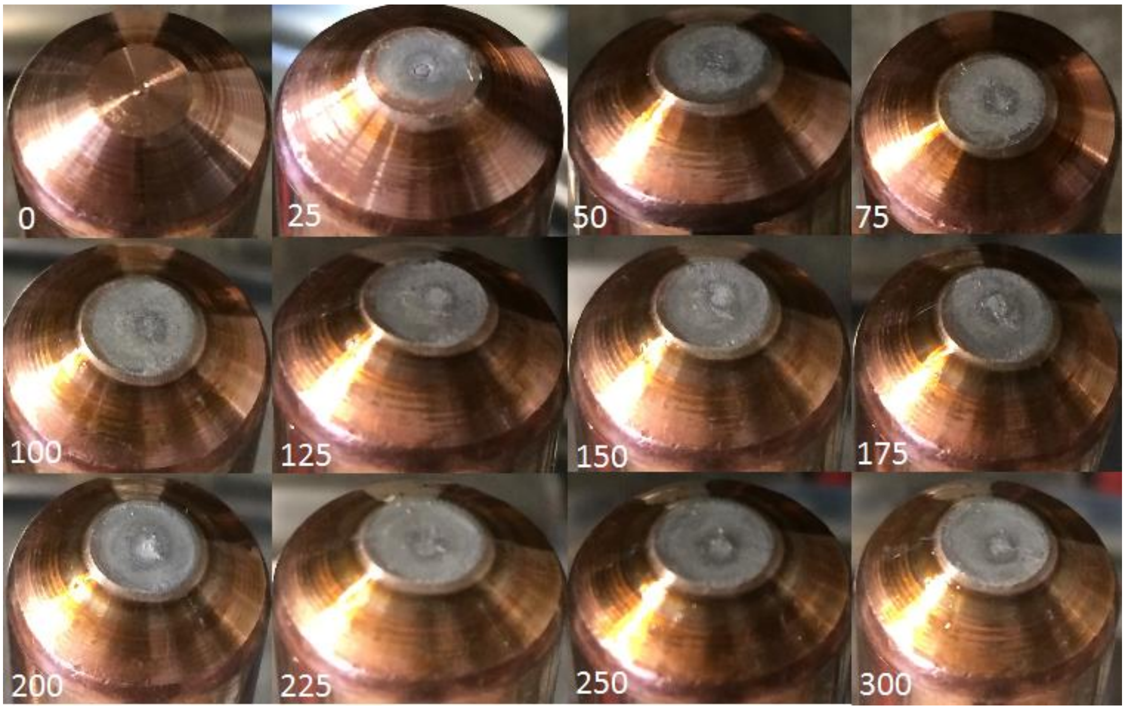

Figure 10. Continuous wear of cap from the first spot to spot number 300.

The first new cap to be tested was the TiB_2-coated molybdenum cap. At the first try the process parameters from the earlier tests were used, presented in Table 3. These parameters resulted in a hole through the two sheets. The result can be seen in Figure 11.

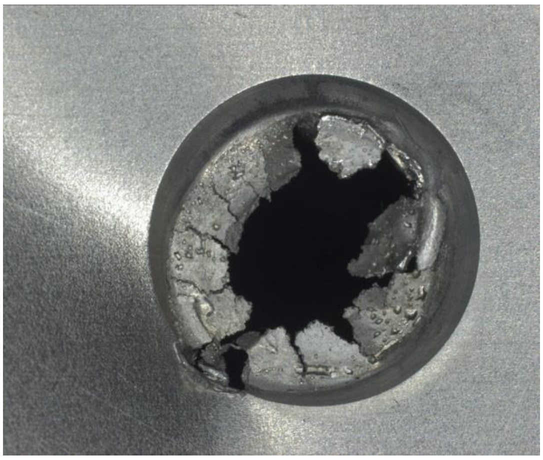

Figure 11. Hole through sheets from welding with TiB_2-coated Mo-caps and process parameters as presented in Table 3.

The contact surface of the two caps used for this weld can be seen in Figure 12.

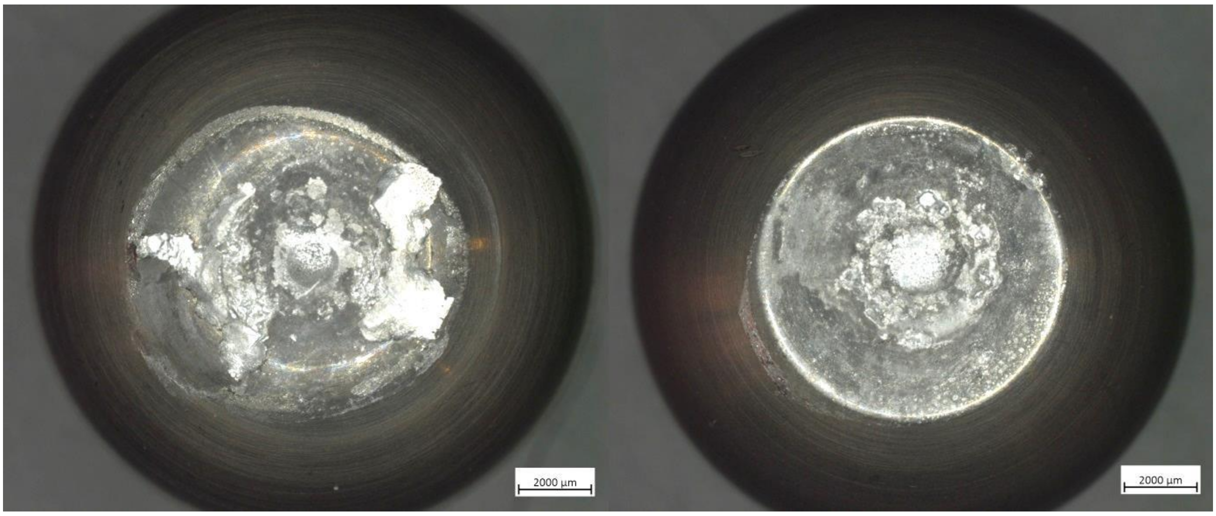

Figure 12. Caps used for weld shown in Figure 11, upper cap to the left and lower cap to the right.

The next step in the experiments with the TiB_2-coated caps was to try to find optimal process parameters. However, no parameters which resulted in an approved nugget size were found. The optimization of the parameters were done by decreasing the current level to 5 kA, thereafter the current were increased gradually in steps of 0,5 kA and the nugget size were measured. The lower current levels, 5-7 kA resulted in no nugget formation. In the current range of 7,5-9 kA a small nugget was developed. However, the nugget did not reach the required size and did also contain of cracks. Spatter occurred at the current level of 9,5 kA. Figure 13 shows a nugget welded with 9 kA with cracks in the centre and Figure 14 shows surface spatter from a spot welded with 10 kA.

Figure 13. Nugget from welding with TiB_2-coated caps and a current level of 9 kA, other parameters kept as presented in Table 3. Cracks can be seen in the centre of the nugget.

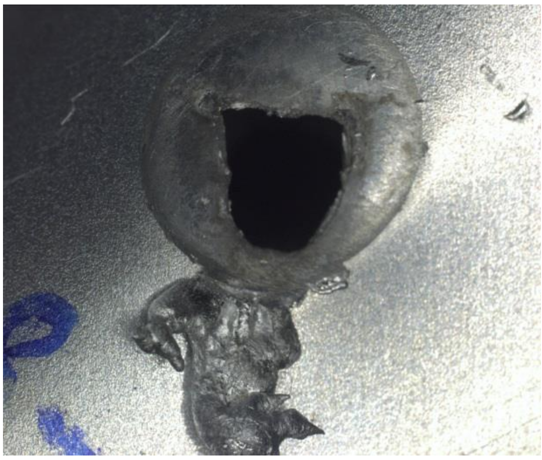

Figure 14. Surface spatter from welding with TiB_2-coated caps and a current level of 10 kA.

The first step of the experiments with the solid un-coated molybdenum caps was to try to find process parameters for an approved nugget size. The test showed that current ranges under 11 kA did not give any nugget formation; a further problem was that surface spatter occurred at these current ranges. The surface spatter is shown in Figure 15.

Figure 15. Surface spatter from spot welded with solid un-coated Mo-cap with weld current at 12 kA.

After further tests the upper cap got stuck to the sheet, as shown in Figure 16. Due to the fact that only one pair of solid un-coated Mo-caps were available no further optimization of the parameters could be done, and the experiments with these caps were terminated.

Figure 16. Solid Mo-cap stuck to upper sheet.

Both the tests with copper caps with a molybdenum plug and with a tungsten plug showed the same behavior. Only one pair of each of these caps was available and in both cases no process parameters could be found in order to achieve an approved nugget size. The tests with Cu-caps with W-plug resulted undersized cracked plugs in the current range of 9-14,4 kA. These tests did also result in a great amount of surface spatter and heavily wear of the caps. Both cracks in the nugget and surface spatter from a spot welded with 13,3 kA can be seen in Figure 17.

Figure 17. Shows both surface spatter and the plug from a spot welded with 13,3 kA. In the centre of the plug cracks can be seen.

These tests were also finished when the W-plug got stuck to the sheet and got loose from the cap. Figure 18 shows the tungsten plug stuck to the sheet. Figure 19 shows the cap without the plug.

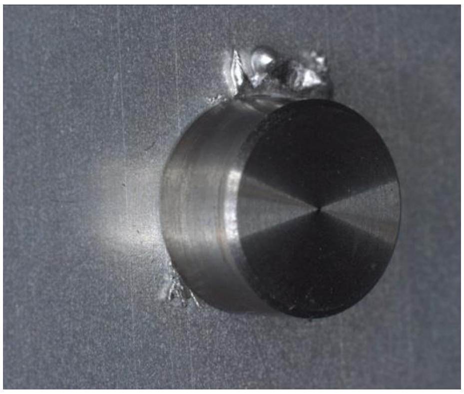

Figure 18. Tungsten plug stuck to sheet, welded with a current of 14,4 kA.

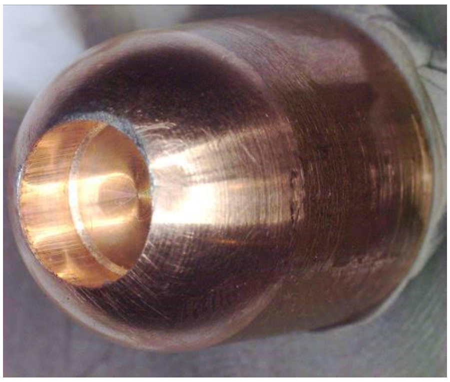

Figure 19. Cu-cap after the tungsten plug got stuck to the sheet.

It could also be seen that cracks had occurred between the plug and the cap in the other electrode. This is shown in Figure 20 together with the heavily wear at the contact area.

Figure 20. Crack between W-plug and Cu-cap after 54 spots. Heavily wear of the contact area can also be seen.

The same behaviour was seen in the tests with Cu-caps with Mo-plug. No process parameters to achieve an approved nugget size could be found. Also in these tests the undersized nuggets contained of cracks and the Mo-plug got loose from the cap and stuck to the sheet. A cracked nugget can be seen in Figure 21, surface spatter is illustrated in Figure 22 and the plug stuck to the sheet is shown in Figure 23.

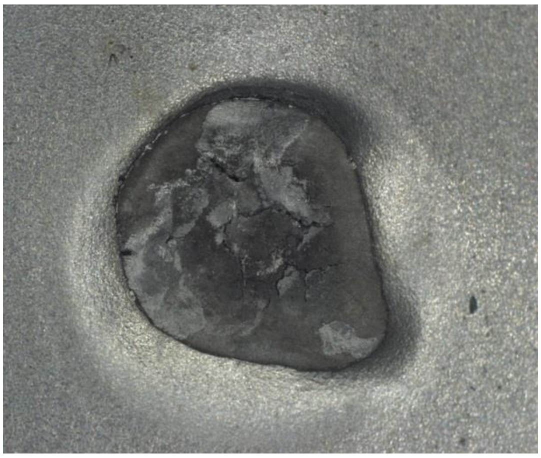

Figure 21. Undersized nugget with cracks in the centre. Welded with 15,3 kA.

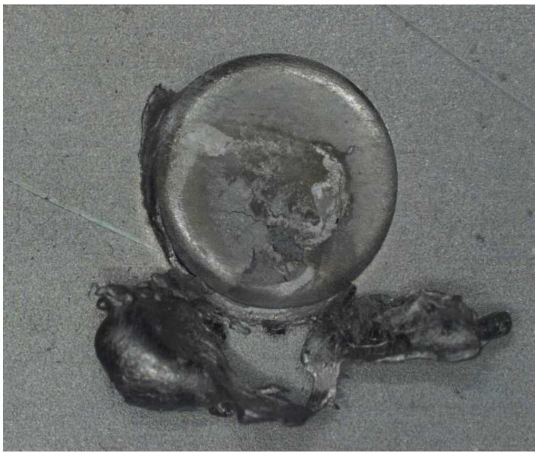

Figure 22. Surface spatter from sot welded with Cu-caps with Mo-plug. Current at 15,6 kA.

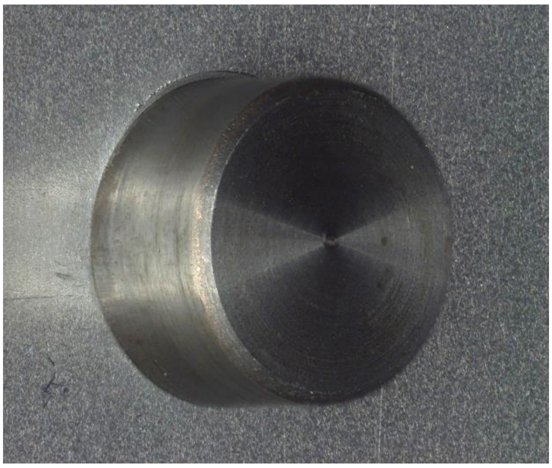

Figure 23. Mo-plug stuck to lower sheet. Welded with a current of 15,9 kA.

The tests with rhodium coated Cu-caps with a molybdenum plug showed the same results. During the optimization of the process parameters the plug in the upper cap got loose from the cap and stuck to the sheet, as shown in Figure 24.

Figure 24. Mo-plug from Rh-coated Cu-cap stuck in the sheet.

In the test with rhodium-coated solid molybdenum caps an approved nugget size was achieved with the process parameters showed in Table 4. A nugget welded with these parameters is showed in Figure 25. The nugget suffers from hot cracking.

Table 4. Process parameters for lifetime test with Rh-coated solid molybdenum caps.

Force [kN]	Squeeze Time [ms]	Current [kA]	Weld Time [ms]	Hold Time [ms]
2,5	700	17,5	120	800

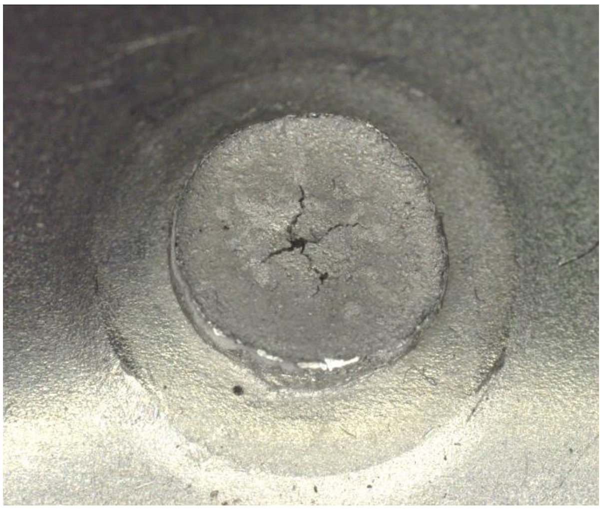

Figure 25. Nugget welded with Rh-coated solid Mo-caps and process parameters as presented in Table 4 .

However, due to heavily surface expulsion no more than 27 spots were welded with these caps. A comparison of the upper cap before and after 27 welded spots is presented in Figure 26. The surface spatter from the 27th spot can be seen in Figure 27.

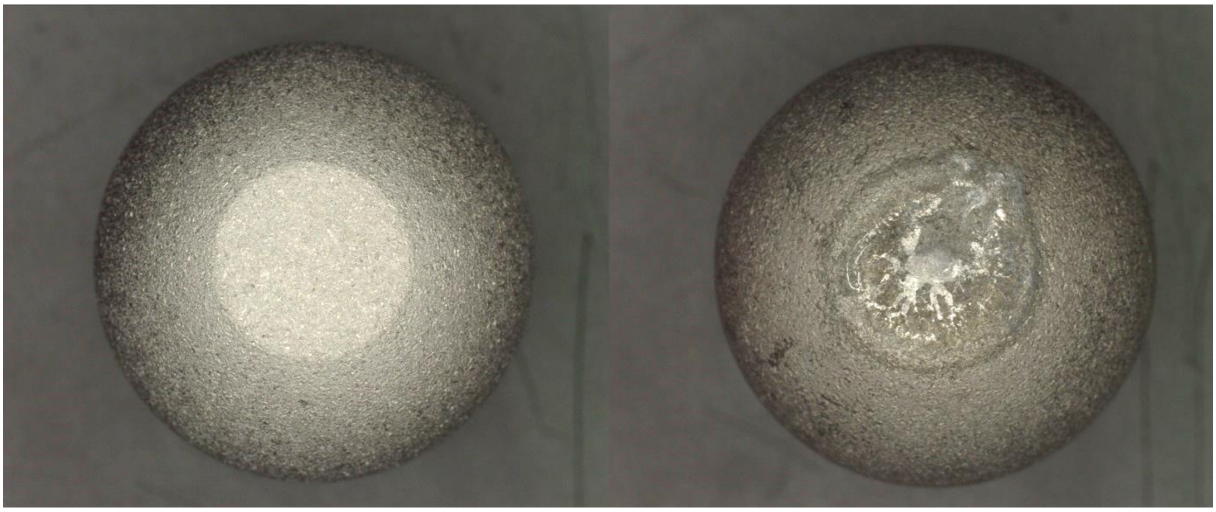

Figure 26. Comparison of new rhodium coated cap, to the left, and after 27 spots, to the right.

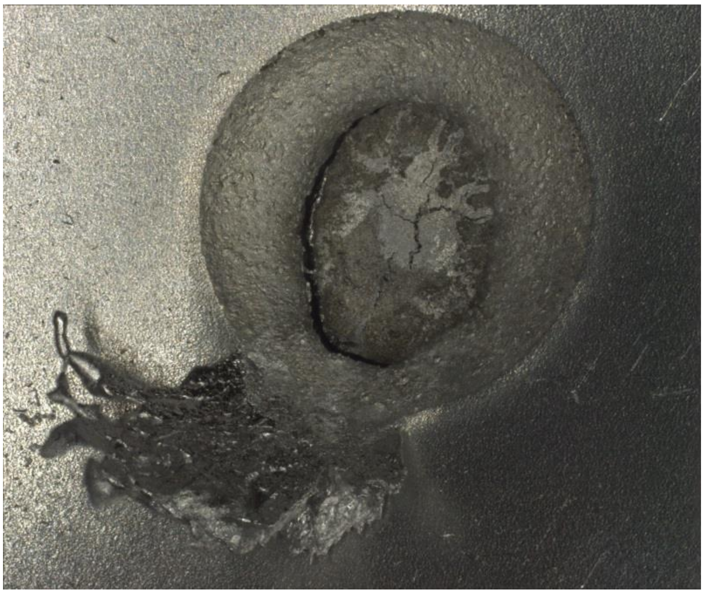

Figure 27. Surface spatter from spot number 27 welded with Rh-coated Mo-caps.

6.2 Laser cleaning

During the experimental part it was concluded that cleaning the sample in a circular fashion in comparison to a row-wise mode gave a shorter cleaning time and better results by visual inspections. However, the row-wise method was less tedious to setup and gave an uneven sputtering, since the center point of the sample is always ablated throughout the cleaning procedures in contrast to the outer parts.

Cleaning in a circular mode

- Faster
- Gave visually the best results
- Optimization more tedious and more important
- Uneven sputtering (more in the center)

Cleaning row-wise

- Easier to set up
- More accurate
- Give rise to lines

- Slower

However, due to the clearly visible artifacts after a row-wise cleaning the circular mode was used throughout the experiments. As shown in Figure 28 and Figure 29, despite using a laser not perfectly suited for this task, the major part of the aluminum was removed during the cleaning procedure.

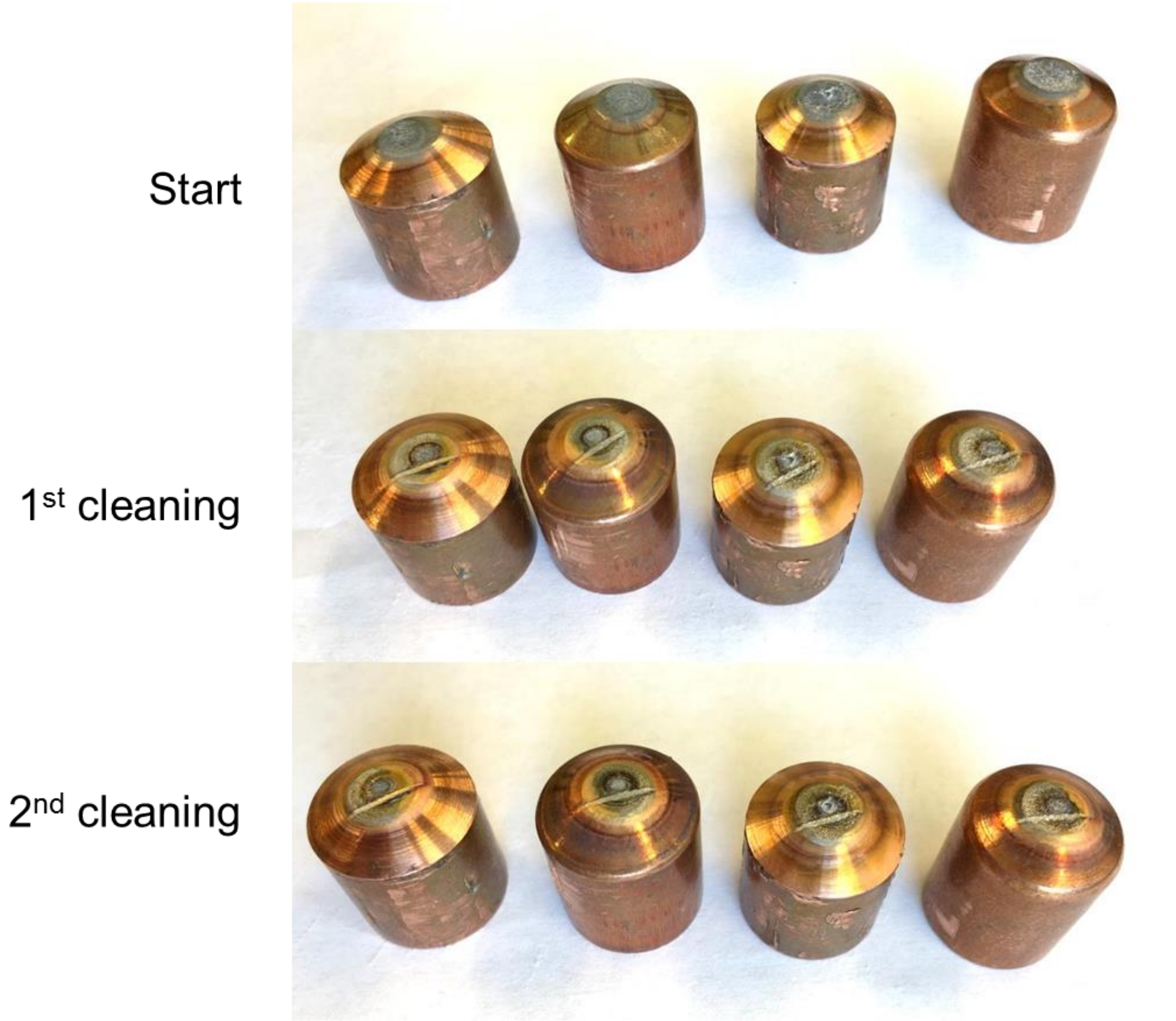

Figure 28. Picture showing the results from a circular cleaning procedure using 10 shots/s during a 15s spin.

Figure 29. A close-up of the left cap in Figure 24 above.

By incorporating a spectrometer and a focusing lens it was clear that aluminum decreased with the number of pulses while the copper lines were enriched, see Figure 30.

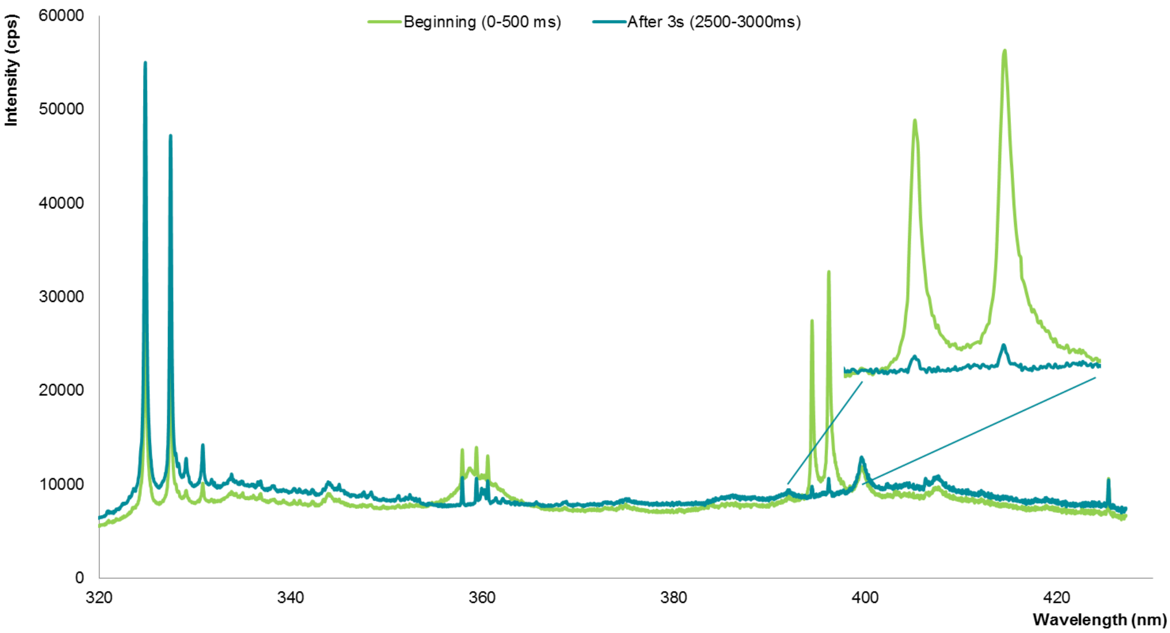

Figure 30. Spectral analysis showing how the aluminium decreased with number of shots. Two of the aluminium lines are enlarged to the right.

The change in height and contact area due to conventional dressing and laser ablation is presented in Figure 31 and Figure 32.

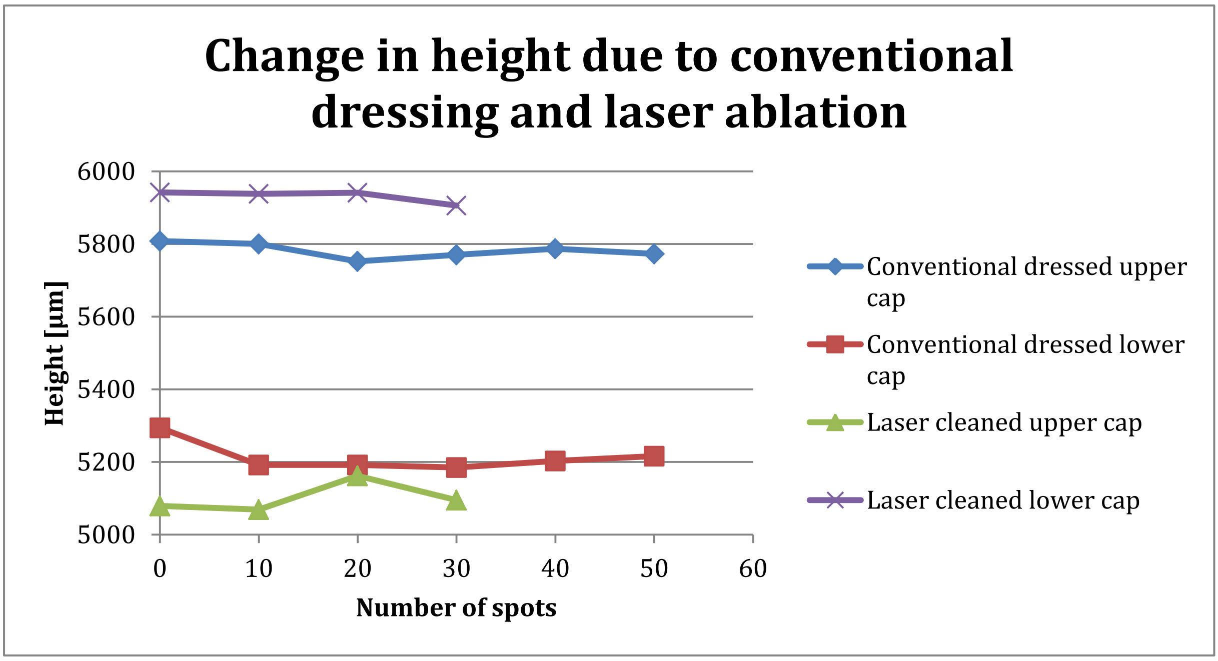

Figure 31. Change in height due to conventional dressing and laser cleaning.

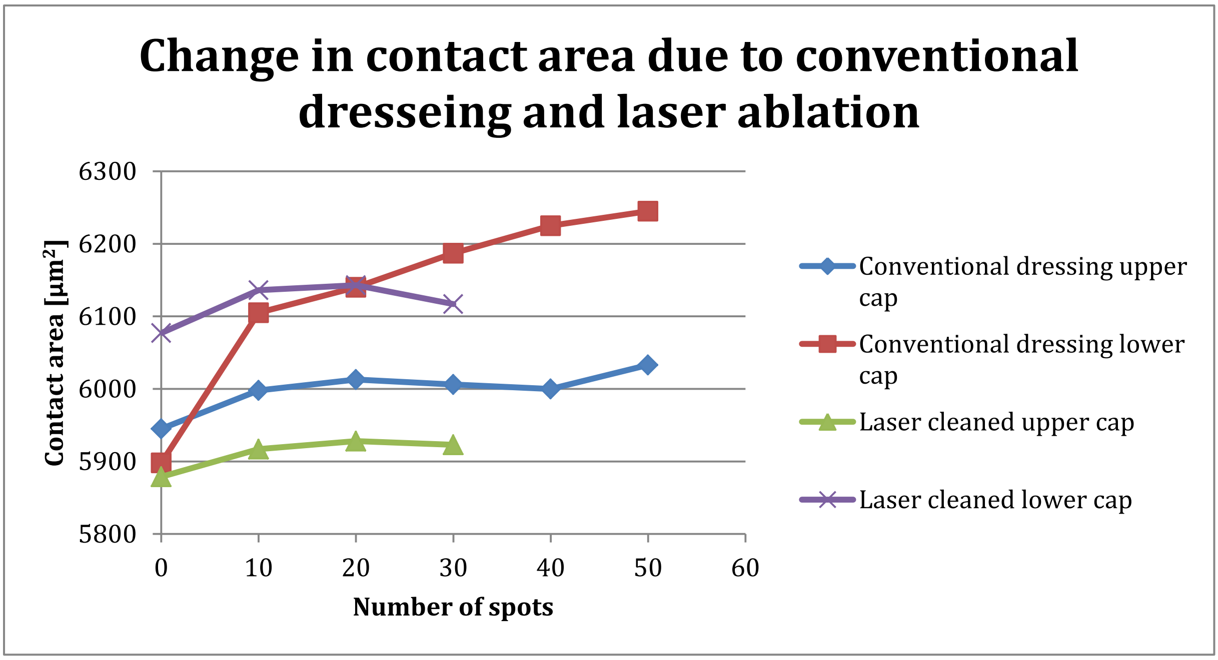

Figure 32. Change in contact area due to conventional dressing and laser cleaning.

As can be seen in Figure 31 and Figure 32 the tests were cancelled after 30 spots. This was due to the insufficient cleaning which caused the same phenomenon as described in chapter 6.1, where the caps got stuck to the sheets. The continuous wear of the electrode caps from these experiments can be seen in Figure 33 and Figure 34.

Figure 33. Continuous wear of electrode cap, dressed with conventional dressing after every 10th spot (from left to right: 0-10-20-30-40-50 spots).

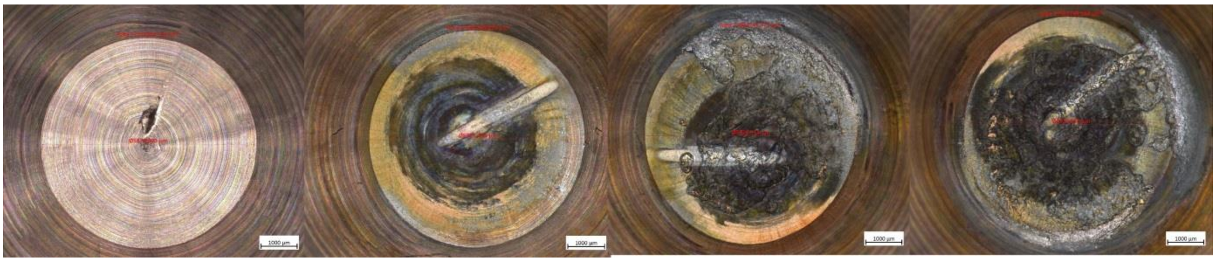

Figure 34. Continuous wear of electrode cap, dressed with laser cleaning after every 10th spot (from left to right: 0-10-20-30 spots).

6.3 Results and deliveries to FFI

The current concept study (pre-study) project has been completed as intended, although the results show that further work needs to be done. Since the project budget was limited only a small optimization work could be done for both the coated caps welding parameters and the laser ablation.

The problems with aluminium welding within the automotive industry has been highlighted and described. Two innovative ways of creating a profitable welding scenario for future light-weight vehicles has been studied according to the aim of the project. A full project application is planned and will continue where this pre study ended. The full project will have a good position to reach the aims as shown in potential within these innovative methods for aluminium welding.

7 Dissemination and publications

7.1 Knowledge and resultdissemination

Hur har/planeras projektresultatet att användas och spridas?	Markera med X	Kommentar
Öka kunskapen inom området	X	
Föras vidare till andra avancerade tekniska utvecklingsprojekt	X	A full project is planned
Föras vidare till produktutvecklingsprojekt	X	After full project
Introduceras på marknaden	X	After full project
Användas i utredningar/regelverk/ tillståndsärenden/ politiska beslut		

7.2 Publications

No external publications have been produced within this project.

8 Conclusions and future work

8.1 Conclusions

Based on the experiments performed in this study with alternative materials for electrode caps the following conclusions are due:

- Cu caps with Mo- or W-plug cannot be used for spot welding aluminum sheets
- TiB2-coated Mo-caps cannot be used for spot welding aluminum sheets
- Mo-caps, both with and without coating, gives a change in welding scenario which results in high heat during the process
- Rhodium coated Mo-caps can be used for spot welding aluminum sheets. However,
- The number of weld spots before surface expulsion were almost the same as for standard copper-alloy caps.

The experiments in this project did not show an increased lifetime of the rhodium coated Mo-caps compared to the commonly used copper-alloy caps. However, since no optimal process parameters were found for the new caps, it is not possible to fully conclude if an increased lifetime of the caps is achievable. The main problem in these tests were the too high temperature in the interfaces between caps and sheets, leading to accumulation of aluminium on the electrode tip, which in turn resulted in more heat at the interfaces between caps and sheets, and finally surface expulsions in early stages of the tests. It is possible that the temperature can be reduced by, for example; solid Cu-caps with Rh-coating, decreased distance from the cooling water to the electrode tip or an increased contact area between the electrode tip and the sheet. A larger contact area would decrease the current density in the interface which in turn would decrease the contact resistance.

The laser cleaning procedure can be concluded in the following bullet points:

- High potential
- Gives no residues
- Can easily be automated
- Can be further developed to clean until only copper visible (LIBS)

The most robust lasers are typically the diode pumped Nd:YAG lasers with ns pulse-length. However, also the short pulse-length lasers are now becoming more robust and easy to use. It would be highly interesting to test for example the EKSPLA Atlantic 60 laser which has 1 MHz repetition rate, average power of 60 W (60 – 150 µJ per pulse), and 15 ps pulse-length. A more safe option (in terms of robustness) however is to aim for a more powerful ns laser. SPI red Energy G4 fiber laser is specifically designed for ablation and drilling. It has 70 W average power, and up to 1 MHz repetition rate. In addition the beam profile can be flat-top which means that a wider area may be ablated. Robust ns lasers are in the range € 10,000 – € 20,000 and the fs are available from about € 30,000.

8.2 Future work

The purpose with coated caps is to achieve “infinite” life length without dressing. In order to evaluate if it is possible to increase the lifetime of rhodium coated caps up to thousands or tens of thousands of weld spots, a complete optimization of the process parameters is needed. If it is possible to achieve an approved nugget size with these parameters a complete lifetime test can be performed and compared to the test with the Cu-caps made in this project. It would also be interesting to add coated Cu-caps to the test matrix in order to investigate if the increased thermal conductivity and decreased electrical resistivity will increase the weld quality or if the higher ductility will damage the coating too much. Another interesting experiment would be to evaluate if a decreased distance from the cooling water to the electrode tip will reduce the temperature at the interface between electrode and sheet, and thereby reduce the accumulation of melted aluminium on the electrode tip. It would also be interesting to evaluate if a cap with a larger contact area will decrease the contact resistance in the interface between the caps and the sheet and thereby increase the weld quality.

There are several ways of improving the laser cleaning procedure. Two major outlines are presented below:

- Faster laser pulses (e.g. from 20 Hz to 1MHz)
  - → Can remove more at the same robot rotation speed
  - → or deeper penetration depth
  - → or faster cleaning procedure
- Different lenses
  - → More focused
  - → Better defined laser spot

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