LEAK TIGHTNESS OF MAGNETIC PULSE CRIMPED JOINTS

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Abstract The goal of this master thesis is to realize and investigate leak tightness of joints produced by the electromagnetic pulse (EMP) crimping process. This way of joining metals has gained more attention lately. With EMP welding, leak tight joints can already be achieved. However, the crimping process has some major advantages over EMP welding like the fact that more material combinations are possible and it requires less energy. To realize the leak tightness, two kinds of sealing materials are used: O-rings and adhesives. The workpieces consist of an aluminium or stainless steel tube which is crimped on a solid aluminium mandrel with circumferential grooves in it. First, some preliminary tests are performed to determine how much the tubes deform in the grooves. This deformation mainly depends on the applied charging voltage and the geometry of the groove. With this information, it is possible to estimate the amount of compression an O-ring would undergo when placed inside this groove. On other workpieces, adhesives will be applied. Several test procedures can be conducted on the parts to investigate leak tightness. The results of a helium test and a pressure burst test on the first test series conducted at the Walloon research centre CEWAC already showed that the use of O-rings can be effective.

Keywords: electromagnetic pulse crimping; leak tightness; leak test; joints

1 INTRODUCTION

In the electromagnetic pulse crimp process, magnetic forces are induced by a very fast and high current discharge in a coil. These forces can be used to deform or join metal workpieces. The high current is provided by a capacitor bank (Figure 1). This capacitor bank stores energy from the net for a few seconds until the required charging voltage is reached. At that moment, a high current switch closes, resulting in the formation of an oscillating electrical circuit. The high current is discharged in a ring-shaped coil in which a tubular workpiece is placed. According to Lenz's law, the magnetic field which is generated by the current in the coil induces eddy currents in the electrically conductive tube. These eddy currents generate a secondary magnetic field, which repels the field induced by the coil. The repelling forces result in radial deformation of the tube. These forces can be used for crimping, welding, forming or cutting [1].

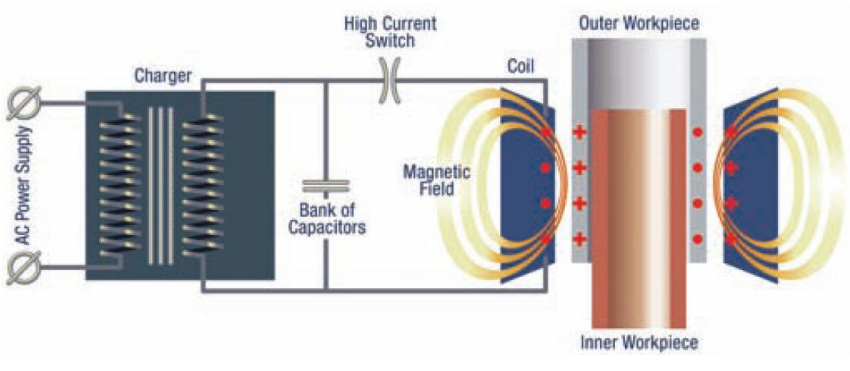

Figure 1 Principle of the electromagnetic pulse generator and the coil [2].

The investigations in this master thesis are part of the project 'PUSLCRIMP – Investigations of magnetic pulse crimping of tubular overlap joints with or without filler material'. The partners of this project are the Belgian Welding Institute (BWI), OCAS (Belgium), Gesellschaft für Schweistechnik international - GSI SLV München (Germany) and Induktion Fügetechnik Fertigungstechnik - IFF (Germany). One of the goals of this project is the development of a new variant of the process for achieving gas tight crimp connections. So far, little effort has been done to investigate leak tightness of EMP crimped joints. Therefore, this project attempts to exceed the international state-of-the-art on this subject. In this master thesis, rubber O-rings and adhesives are used. The objective is to achieve gas tightness with both sealing materials.

2 HOW CAN LEAK TIGHTNESS BE ACHIEVED

As mentioned before, two kinds of sealing concepts are used in this master thesis: O-rings and adhesives. Both have specific advantages, depending on the application. Originally, soldering was also considered as an option, but the high temperature required to melt the solder (in the order of 450 °C) makes this a less attractive alternative.

2.1 O-rings

The use of O-rings in EMP crimped joints to obtain leak tightness has been suggested in [1], [3], [4] and [5]. However, it should be noted that those are merely suggestions for further research as none of the authors actually proved it on an experimental basis. Figure 2 shows an example of a typical suggestion for the use of O-rings in EMP crimped joints.

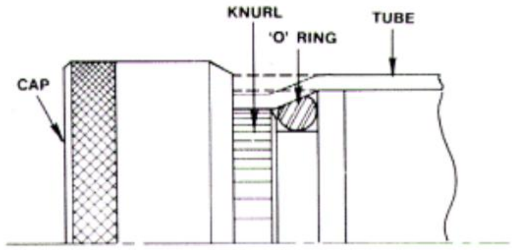

Figure 2 Suggestion for the use of an O-ring in EMP crimped joints [4]

The O-ring concept has already proven its sealability in a lot of applications. It is a very common method for both static and dynamic sealing. They can be used for very high pressures, in some cases more than 1000 bars [6]. O-rings are a cheap, effective solution and they are easy to use.

An O-ring seal has two essential parts: the O-ring and the gland. A seal is obtained when an O-ring is squeezed between mating components, thereby creating zero clearance and preventing the escape of fluids through the clearance gap [7]. When placed under differential pressure, the O-ring is forced to “flow” within the groove towards the clearance gap. As the O-ring flows against (and slightly into) the gap, it produces zero clearance and prevents the sealed substance from leaking.

The working principle is illustrated in Figure 3. When pressure is applied, the ring acts as if it were a viscous fluid with very high surface tension. The O-ring deforms and the contact zone with the mating surfaces increases. If the seal is under high pressure, the clearance gap increases and the rubber ring is forced into it. This is called extruding. When the pressure is further increased, the surface tension of the elastomer is no longer sufficient to resist flow and the material extrudes (flows) severely into the clearance gap. In case of fluctuating pressure, small parts (nibbles) may be torn from the ring at the low pressure side during the pressure drop, because of reduction of the clearance gap and the retraction of the ring. Eventually a leak path forms and the seal fails [7], [8], [9].

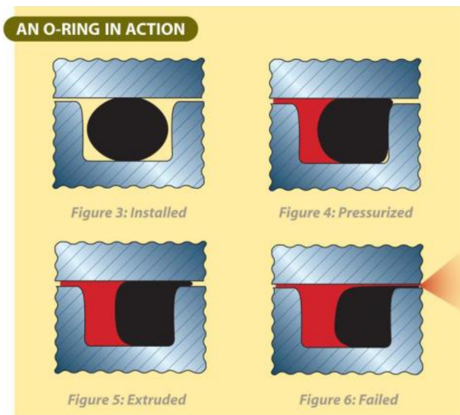

Figure 3 Working principle of an O-ring [7].

During the EMP crimping process, the O-rings have to withstand a high compression rate and elevated temperatures. Heat generation is caused by both the Joule-effect from the currents that flow in the tube and

the deformation energy [10]. Given that the elevated temperature only occurs for a small amount of time, the ageing of the O-rings is expected to be limited.
The O-ring material that will be used in this work is NBR with compound number 36624. The temperature range of NBR 36624 is between -30°C and 120°C [8].

2.2 Adhesives

The success of every adhesive bond depends on certain physical properties of the connecting materials and the applied adhesive, such as adhesion and cohesion. Because of the small range of the intermolecular forces acting between the adhesive and the adherent, the adhesive must have a low viscosity and surface tension to fill all the gaps between the roughness peaks. To realize a full coverage of the surface for optimal adhesion, contaminants must first be removed by cleaning [6]. Because of the tight connection between the adhesive and the parent materials, a leak proof joint can be obtained. The strength of the adhesive connection also contributes to the torsional stiffness of the joint [11].

In [12], GSI SLV reports on experimental attempts to obtain leak tightness by using adhesives. For both the mandrel and the tube aluminium EN-AW 6060 was used. Two types of adhesives were evaluated: Loctite 9450 2K-Epoxy and Loctite 9492 2K-Epoxy. The first adhesive showed a lack of resistance against the high crimping process temperatures. The second one has an extended temperature range and withstood the developed heat during crimping. The results were most promising for specimens where the adhesive was applied outside the geometry of the groove, while there is a clear evidence of gas inclusions when the adhesive was applied at the bottom of the groove (see Figure 4). The central figure indicates the position of the adhesive.

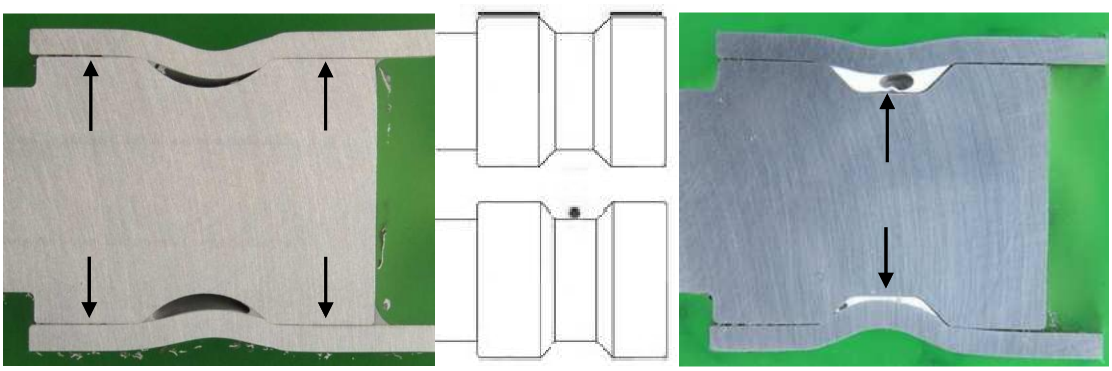

Figure 4 Cross sectioned EMP crimped joints sealed with adhesives [12].

The disadvantage of using adhesives is that the surfaces of both the tube and the mandrel must be degreased, cleaned and sometimes treated with chemicals, especially when using aluminium. Furthermore, when the adhesive is applied, the connection must in some cases cure for days [13].
In this work several types of adhesives and sealants will be tested: liquid adhesives (Loctite 638, Loctite 246, Loctite 14486), paste (Loctite 660, Loctite 510, Loctite 574) and tape (Terostat 7, Loctite 249).

3 EVALUATING LEAK TIGHTNESS

When investigating leak tightness, one can ask three questions. The first and straightforward question is if there is a leak or not. If so, what is the size of the leak and where is the leak located? Some leak test procedures can only give an answer to one or two of these questions. In those cases, different tests must be conducted to fully characterize the leak(s). This section focuses on non-destructive inspection techniques. Destructive evaluation techniques like the pressure burst test and cross sectioning will be performed on the test specimens as well.

3.1 Bubble test

The bubble test is a very basic and simple method. The specimen to be tested is submerged in a water tank and then pressurized with a gas (usually air). If there is a leak, the pressurized gas will escape through it, resulting in bubble formation [14]. With this test, one can determine the location of the leak.
Although it is simple and quick, there are some problems associated with this testing method. The test only gives a qualitative result, so it cannot be correlated to other quantitative testing methods. The mechanisms of air transport into water and bubble formation as well as other sources of air bubbles (leaks from fixtures, bubbles from air trapped on surfaces, etc.) are biased and prevent reliable leak detections [15].

3.2 Pressure decay test

In the pressure decay method, a specimen is pressurized with a gas until a certain threshold value is reached. Then the supply is cut off, so no more gas can get in and the only way the gas can get out is through leaks. If leaks are present, the pressure in the specimen will drop. This test gives a quantitative result as the pressure decrease ΔP can be related to the leak rate Q using the equation (1).

$$Q = \frac{\Delta P\ [mbar] \cdot V\ [l]}{\Delta t\ [s]} \tag{1}$$

V stands for the volume in which the pressurized air is trapped. Δt is the elapsed time during the pressure decrease.

3.3 Combination of bubble test and pressure decay test

In [14], it is proposed to combine the bubble test with the pressure decay test. A pressure decay test is performed with the workpiece submerged in water. This way, the advantages of both test methods are combined and some drawbacks are compensated. The combination method gives a quantitative result and the leak position can be determined. The test configuration used in our work is shown in Figure 9.

3.4 Gas detection methods

Gas detection methods are an accurate way of detecting leaks and measuring leak rates. These methods use a tracer gas, preferably with molecules as small as possible. Depending on the method, the tracer gas goes from the surroundings through the leaks to the inside (if there is a vacuum inside the workpiece) or the other way around if the workpiece is pressurized with the tracer gas. It is important that the joints are sealed at the other side of the tube when conducting these tests, so any gas that escapes goes through leaks in the crimped connection.

The tracer gas can be detected in several ways. First there is the thermal conductivity sniffing. In this method the thermal conductivity of the gasses sucked up by a scanning probe is measured. A leak is found if the conductivity shifts while scanning in the surroundings of the leak. A second method is halogen sniffing. A highly positive ion concentration reveals the presence of the halogen tracer gas. The ion current is a measure for the leak size.

Because of its small molecules, helium is an excellent tracer gas. Therefore the highest accuracy can be achieved with the helium mass spectrometer method. The molecular mass of the gasses is measured, so basically any tracer gas can be used. This method has been carried out in CEWAC to test the workpieces from the first test series (see 4.3).

3.5 Comparing different tests

In

Table 1, the three basic questions are answered for different test methods. It can be seen that the pressure decay method and the bubble immersion method are somewhat complementary. The combination method has a minimum detectable leak rate of 10^{-4} atm·cc/s (= 1,013·10^{-4} mbar·l/s) and allows leak location detection. When more accuracy is needed, one can switch to the gas detection methods (last three rows of the table).

Table 1 Comparison of leak detection methods [16]

Method	Minimum Detectable Leak (atm-cc/sec)	Leak Rate Measurement	Leak Location
Pressure Decay	Time Limited, Typically 0.01	Yes	No
Ultrasonic	0.01	No	Yes
Chemical Penetrants	0.001	No	Yes
Bubble Immersion	10^{-4}	No	Yes
Thermal Conductivity Sniffing	10^{-5}	Yes	Yes
Halogen Sniffing	10^{-9}	Yes	Yes
Helium Mass Spectrometer	10^{-11}	Yes	Yes

4 EXPERIMENTS

4.1 The crimping process in practice

All the pulse crimping experiments in this thesis will be performed using a Pulsar MPW 50/25 magnetic pulse system. To perform a series of experiments, first a suited field shaper must be installed (see inset on Figure 5). This component concentrates the magnetic field onto a small area, which results in a higher magnetic pressure. For every diameter of the test specimens, a different field shaper is needed.

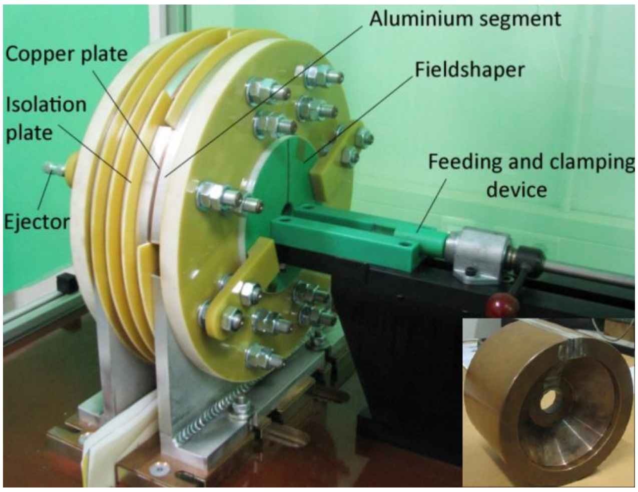

Figure 5 The coil without (left) and with (right) the field shaper in place

The next step is to insert the workpiece in such a way that the area of the part which needs to be crimped is positioned just in the middle of the fieldshaper. The workpiece itself has to be supported too, so no relative movement of the tube, the mandrel or the coil is possible.

Once the parts are positioned, the machine can be switched on. On the control unit, the required charging voltage can be set. Then the master button is pushed, which charges the capacitors. Within a few seconds, the current is discharged and the part is crimped. The crimping process lasts only about 20 to 25 microseconds. The workpiece can be taken out of the coil directly after the process has taken place. The part is now ready to undergo the necessary tests.

4.2 Test specimens

The test specimens consist of two pieces: tubes and mandrels. So far, the material used for both the outer tubes and the mandrels is aluminium EN AW-6060 T6. The tubes have a wall thickness of 1,5 mm and an outer diameter of 45 or 50 mm. The first test series was developed for the feasibility evaluation of O-rings. The test matrix is presented in Table 2. The mandrels for these preliminary experiments with O-rings are shown in Figure 6. As can be seen, the only geometrical parameter that was varied is the groove depth. The groove radius is set to 1,5 mm for both parts, the groove with is 7 mm.

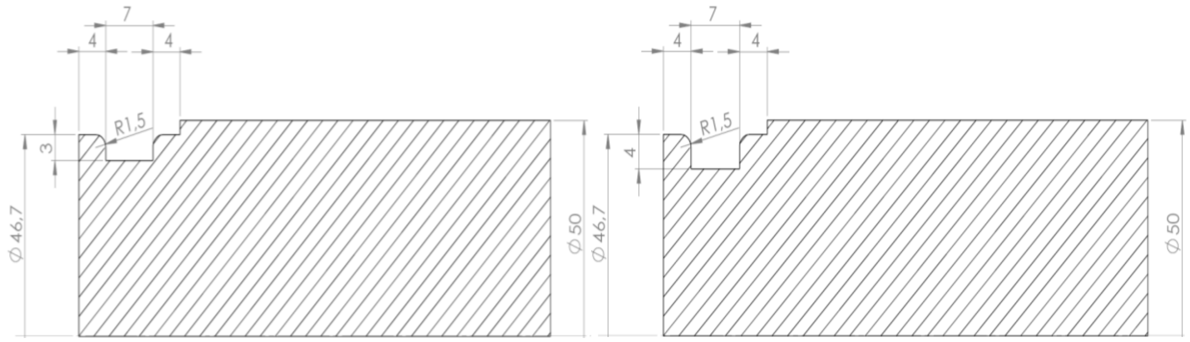

Figure 6 Design of the mandrels for the evaluation of O-rings.

Table 2: Test matrix of the first test series

Name	Charging voltage (kV)	Groove depth (mm)	Sealing material
PC-AlAl-1	10	3	no rings
PC-AlAl-2	12	3	no rings
PC-AlAl-3	12	3	2 rubber rings 40x2
PC-AlAl-4	11	3	2 rubber rings 40x2
PC-AlAl-5	13	3	2 rubber rings 40x2
PC-AlAl-1.1	12	4	no rings
PC-AlAl-2.1	11	4	no rings
PC-AlAl-3.1	10	4	2 rubber rings 38x3
PC-AlAl-4.1	11	4	2 rubber rings 38x3
PC-AlAl-5.1	9	4	2 rubber rings 38x3

First experiments were done without O-rings, to see how much the tube deforms inside the groove. This information can be used to estimate how much an O-ring would be compressed if it were placed in a corner of the groove. For the same groove depth, several charging voltages were used. After each experiment, the specimens were cross sectioned and marked. In Figure 7, two examples of workpieces are shown. The depth of the groove is 3 mm for both parts, but the left part (PC-AlAl-2) was crimped with a charging voltage of 12 kV and the right part with 10 kV. One can clearly see the difference in deformation.

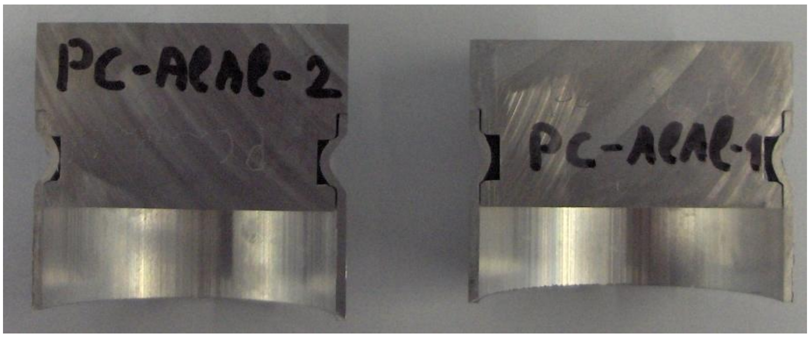

Figure 7 The effect of charging voltage on the deformation.

The deformation of the right part is assumed not to be sufficient to squeeze an O-ring. The same geometry and charging voltage as for the left part shown on Figure 7 were used to crimp a work piece with two O-rings put at the corners of the groove. Figure 8 shows the mandrel with the O-rings in place. This part has a groove depth of 3 mm and has been crimped with a charging voltage of 12 kV. The rubber rings have an inner diameter of 40 mm and a cross section diameter of 2 mm.

For the tests with adhesives, tubes with an outer diameter of 45 mm will be used. An example of a drawing of a mandrel that will be used with adhesives is also shown in Figure 8. It is planned to change three different parameters: the charging voltage, the depth of the groove and the kind of adhesive.

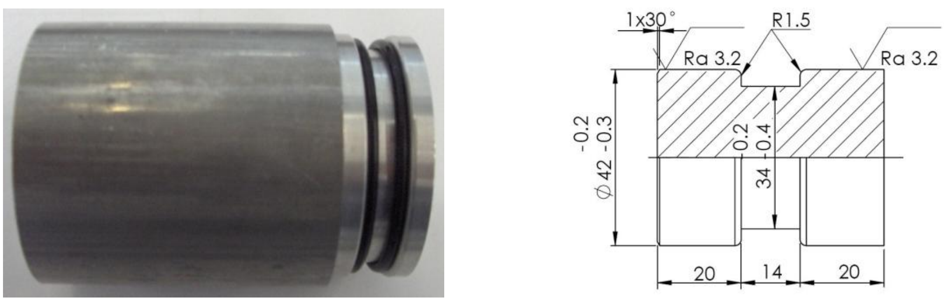

Figure 8 Mandrel with two O-rings in the corners of the groove (left) and drawing of a mandrel that will be used with adhesives (right)

4.3 Leak tests and pressure burst tests

Some parts from the test series with O-rings were sent to the research institute CEWAC (Centre d'Etude Wallon de l'Assemblage et du Contrôle des Matériaux). There the test specimens were subjected to a helium leak test and a pressure burst test. During the burst test, hydraulic pressure is applied at a controlled rate until the specimen bursts. This method provides a quantitative measurement that reflects the strength of the connection. The ideal situation is when the burst occurs in the parent material rather than in the joint itself.

The results for specimens PC-AlAl-3 and PC-AlAl-5 are shown in Table 3. In the leak test, first the surrounding helium concentration (SC – scanned concentration) was measured as a reference. Then the surface was scanned for leaks, resulting in the measured concentration (MC). No significant leak rate was detected at the surface of the two specimens as the measured concentration and the surrounding concentration are approximately the same. This means that the O-rings have been effective. The measured burst pressure (BP) was higher for the second specimen than for the first one. This can be correlated to the higher charging voltage that was used for PC-AlAl-5.

Table 3: Test results from CEWAC

Name	**SC (mbarl/s)**	**MC (mbarl/s)**	**BP (bar)**
PC-AlAl-3	$2{,}4\cdot10^{-10}$	$2{,}2\cdot10^{-10}$	86,0
PC-AlAl-5	$1{,}8\cdot10^{-9}$	$1{,}7\cdot10^{-9}$	104,2

For preliminary investigations of leak tightness, a test rig (see Figure 9) was built in previous work related to EMP welds [14]. A redesign is carried out to make it suitable for the test specimens produced in this work.

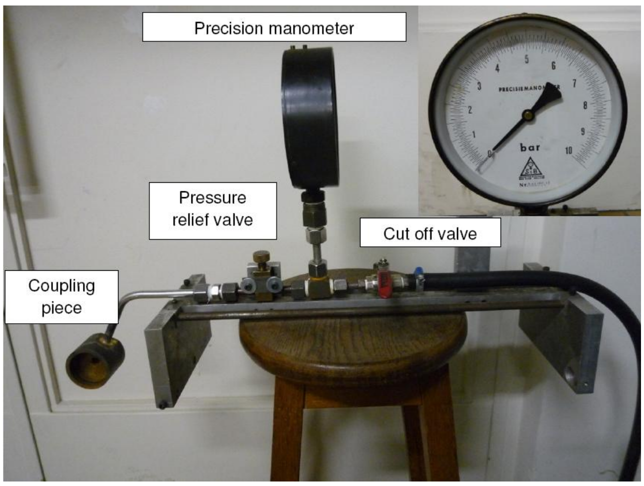

Figure 9 Air pressure test configuration [14]

5 CONCLUSIONS

Within the framework of the PULSCRIMP project, the aim is to produce leak tight joints using the EMP crimping process. Two design concepts are considered, one using O-rings and the other based on adhesives. The results from the helium tests performed at CEWAC proved that the use of O-rings can be effective. The workpieces for the concept based on adhesives have been designed. To perform a leak test on the produced specimens, a pressurized air test rig has been redesigned. Its working principle is based on a combination of a bubble test and a pressure decay test. The results of these preliminary experiments will point out the most important parameters and the best combinations. Further investigation on those combinations will then be conducted.

6 ACKNOWLEDGEMENTS

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REFERENCES

[1] R. Schäfer, P. Pasquale en S. Kallee, „Industrial application of the electromagnetic pulse technology," Alzenau, Germany, PSTproducts Gmbh, 2009, pp. 2-3.

[2] V. Shribman en Y. Tomer, „Magnetic pulse technology for improved tube joining and forming," *Tube & Pipe Technology,* pp. 91-95, november/december 2006.

[3] M. V. Wonterghem en P. Vanhulsel, Magnetic pulse crimping of mechanical joints, Master dissertation Ghent University, 2011.

[4] Magneform, [Online]. Available: http://www.magneform.com/pres.html.

[5] J. Broeckhove en L. Willemsens, Experimental research on magnetic pulse welding of dissimilar materials, Master dissertation Ghent University, 2010.

[6] D. Muhs, H. Wittel, M. Becker, D. Jannasch en J. Voßiek, in *Roloff/Matek machineonderdelen*, Den Haag, Sdu Uitgevers, 2007, pp. 620-621.

[7] „0-ring Design & Materials Guide," R.L. Hudson & Company, 2011. [Online]. Available: http://rlhudson.com/O-Ring%20Book/opening.html.

[8] „Sealing Elements: Technical Handbook O-rings," Eriks, [Online]. Available: http://o-ring.info/en/o-ring/Oring-Handbook/ERIKS_SealingElements_TechnicalHandbook_O-rings.pdf.

[9] „Parker O-ring handbook," Parker Hannifin Corporation, 2000. [Online]. Available: http://www.parker.com/literature/ORD%205700%20Parker_O-Ring_Handbook.pdf.

[10] F. Broekaert en M. D. Ketele, An exploratory study into the feasibility of magnetic pulse forming, Master dissertation Ghent University, 2009.

[11] H. Kawamuraa, T. Sawab, M. Yonenoa en T. Nakamura, „Effect of fitted position on stress distribution and strength of a bonded shrink fitted joint subjected to torsion," *International Journal of Adhesion & Adhesives,* nr. 23, pp. 131-140, 2003.

[12] H. Cramer, L. Appel en C. Ableitner, Report „PULSCRIMP - Weiterentwicklung des Magnetimpuls-Crimpens (MPC) von rohrförmigen Überlappverbindungen mit und ohne Zusatzwerkstoff," SLV München, July 2011.

[13] J. Shields, Adhesives handbook third edition, Butterworths, ISBN: 0408013567, 9780408013567, 1984.

[14] J. Verstraete, Magnetic pulse welding, Master dissertation Ghent University, 2011.

[15] „Air Under Water (AUW) - Bubble test and immersion leak testing," ATC inc., [Online]. Available: http://www.atcinc.net/bubble-test.asp.

[16] L. Technologies, „Technical reference guide,” [Online]. Available: http://www.lacotech.com/ProductFiles/997300658_leaktechref.pdf.