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Final report on

"PEM Low Cost Endplates"

Sammenfatning på dansk

I projektet er der udviklet en endeplade til brændselsceller af typen PEM. Den indledende idé var at benytte en sprøjtestøbbar fiberforstærket plast til at fremstille endepladen og dermed udnytte mulighederne for større geometrisk frihed til at sænke vægt og materialeforbrug. Forskellige PPS/glasfiber-kompounds blev fremstillet og testet, så resultaterne kunne benyttes til at optimere designet på computeren med FEM-simuleringer. Det viste sig, at det ikke var muligt at opnå en tilstrækkelig stivhed for endepladen indenfor de geometriske begrænsninger der var sat. Ved de relativt høje temperaturer endepladerne udsættes for, bliver materialet ganske enkelt for blødt. Materialefokus blev skiftet til en højstyrkebetonkomposit. Testemner blev fremstillet og testet så resultaterne igen kunne benyttes til FEM-simuleringer der også tog højde for de støbetekniske begrænsninger betonen har. I udviklingsprocessen skete der også et skift i den måde endepladen opspændes for bedre at kunne udnytte betonens egenskaber. En række endeplader blev støbt i specialfremstillede støbeforme for at kortlægge de optimale procesparametre og en endelig endeplade sendt til afprøvning hos IRD Fuel Cells A/S. Afprøvningsforløbet var en succes. Dog kan gasforseglingen og overfladefinishen forbedres yderligere. Vægten på de udviklede endeplader kan være et problem til nogle anvendelser, selv om den er lavere end for de i dag anvendte endeplader. Vægtaspektet kan evt. behandles i et fremtidigt projekt. Arbejdet har resulteret i en ny endeplade design, hvilket gør staksamlingen enklere og med færre komponenter. Endepladen fabrikation involverer billige metoder, der kan skaleres op, efterhånden som efterspørgslen på brændselsceller tager fart.

Abstract

In the project, an endplate for the PEM-type fuel cells has been developed. The initial idea was to use an injection mouldable fibre reinforced polymer to produce the endplate and thereby exploit the opportunities of greater geometrical freedom to reduce weight and material consumption. Different PPS/glass-fibre compounds were produced and tested in order to use the results to optimize the results on the computer through FEM simulations. As it turned out, it was impossible to achieve adequate stiffness for the endplates within the given geometrical limitations. At the relatively high temperatures at which the endplates operate the material simply goes to soft.

Material focus shifted to fibre reinforced high strength concrete composite. Test specimens were produced and tested so the results again could be used for FEM-simulations which also accounted for the technical limitations the concrete composite has regarding casting ability. In the process, the way the endplate is mounted was also alternated to better accommodate the properties of the concrete composite. A number of endplates were cast in specially produced moulds in order to map the optimum process parameters, and a final endplate was tested at IRD Fuel Cells A/S. The field test was in many aspects successful. However, the gas sealing and the surface finish can be further improved. The weight may still be an issue for some applications, even though it is lower than the endplate currently used. This issue can be addressed in a future project. The work has resulted in a new endplate design, which makes the stack assembly simpler and with fewer components. The endplates fabrication involves low cost methods, which can be scaled up as demand of fuel cells begin to take off.

Introduction

Below is given a description of the progress in the different work packages that describe the progress in the ”Low Cost End Plates” partly financed by EUDP. The work has been divided between the Plastics department at DTI and IRD Fuel Cell Technology. IRD has been providing the endplate specification along with the components that need to be attached to the end plate. Furthermore, IRD has been conducting field tests with the developed end plate. DTI has been focussed on material development, geometrical optimisation, and process development.

WP1 Specification

Injection moulding guidelines

A general guide on development and production of plastic parts which describes the all the steps of mapping the part specification, general construction guide lines, computer aided design, mould flow, finite element mechanics, choosing material and process, the possibilities of welding different parts together, and creating serial production control. IRD worked on the specifications regarding mechanical and chemical properties for the endplates along with information on the loads. A report was provided along with the geometrical data in CAD-files.

Endplate specifications

The Endplate specification is a general specification covering end plates for LT-PEM, HT-PEM, DMFC and low pressure EC stacks (< 10 bar).

The endplates provides both the mechanical base used for clamping the cells together in a stack and the base for attaching the connectors for the air, fuel and cooling manifolds. Functioning as the mechanical base means that the endplates ensures that the cells in the stack are being compressed uniformly over the whole cell surface. This is fulfilled either by having no deflection when compressed or having a small well defined deflection compensated by an equal curvature in the plates making them planar when compressed. The required plate strengths are given below:

- E-Modulus: 20 GPa

- Compressive strength: 550 MPa
- Flexural strength at RT: 450 MPa
- Bøjningsstyrke ved forhøjet T 300 Mpa
- Tensile strength: 320 MPa

The end plates must have holes with threads for the external connections to fuel, air and cooling manifolds. O-ring grooves must be provided for the internal connections to the manifolds. Fulfilling the specifications below will ensure that the connections are gas tight:

- Roughness: contact surface Ra 10-20 µm
- Flatness: < 0,1 mm

A part from these specifications the end plates must be made by a molding process at a price of 50 DKK/plate. Life time must be > 40.000 hours.
The full specification is given Appendix A

An endplate design for LT-PEM stacks was specified for the development work. The end plate made from this design can be used in IRD's present LT-PEM stacks. The design has been improved by substituting the 4 tie rods used when clamping the stack with 2 steel clamps.

WP2 Material Selection & Development
The initial idea was to use a fibre reinforced polymer with high temperature properties suitable for the application. The advantage would be the low cost of injection moulding along with the possibilities of making a complex geometry. The latter would make it possible to save material and thereby reducing weight and cost.
The specifications from IRD dictated a very stiff and strong material which would maintain these properties at high temperatures. A search was conducted and a number of materials were examined. The most suitable were PEI, PAI, PI, and PPS. PPS (polyphenylene sulfide) was chosen based on an evaluation of mechanical properties and price. Some carbon reinforced qualities has a very high E-modulus, but with a subsequent low break elongation. This could render the part to vulnerable for the application with the risk of brittle fractures. Therefore, a number of blends with varying fibre content were compounded, moulded, and tested. The fibres of choice were glass instead of carbon in an attempt to raise the break elongation. The blends were formulated by mixing a quality containing 40 % glass and a pure quality.
The tests were conducted at different temperatures in order to evaluate stiffness and strength. An example of the results are shown in Figure 1 where the left graph shows Young's modulus as a function of fibre load at different temperatures, while the right shows stress – strain curves for different fibre loads at a set temperature.

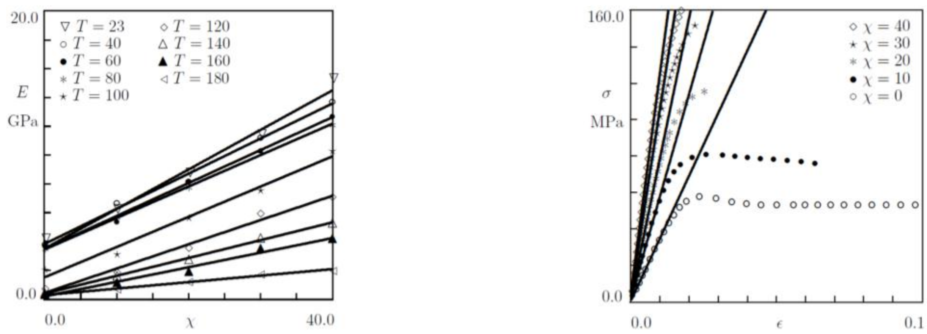

Figure 1 Bending tests were carried out on 200 x 30 x 20mm rectangular bars

The data from the tests showed that the material still had limitations in the high temperature area specified by IRD. After the high temperature data were used to conduct finite element analysis showing that it would be very difficult to reach the goal a new material came into play.

It was discovered that a high strength concrete composite could fulfil all of the requirements for the end plates as they can withstand temperatures well over 80 degrees Centigrade, exhibit the required mechanical and chemical properties, and can be cast to fine tolerances allowing threads to be formed for attaching gas fittings.

Two types of high strength concrete composite were chosen for endplate manufacture. These were:

(a) Type A is a concrete composite which requires 28 days hardening period before achieving an adequate strength and

(b) Type B is a more expensive concrete composite, which can achieve full strength after a few days.

Type A contains a natural sand aggregate resulting in a compressive strength of around 140 MPa whereas Type B, which is more expensive than Type A, contains a calcinated bauxite aggregate which results in compressive strength of 200-220MPa. In addition, whereas the Type A material is allowed to cure (i.e. reach maximum strength) for 28 days, the Type B material can be cured in around 48.

Steel fibres were added to both the Type A and Type B materials to increase toughness and ensure that when the test materials fractured under loading the release in load was gradual and test bars did not shatter in a dangerous manner.

Test bars – bending tests

Before casting the actual end plates a number of bending tests were carried out on 200 x 30 x 20mm rectangular bars (see Figure 1) which were cast in both Type A and Type B concrete composites using the manufacturers recommended mixing procedures.

Figure 2, typical rectangular bar test specimen used to determine bending strength

Three and four point bending tests were carried out using an Instron mechanical testing machine using a cross head speed of 5mm/minute.

The bending strength $\boldsymbol{\sigma_{4PB}}$ under a bending load was calculated from:

$$\boldsymbol{\sigma_{4PB} = 3 F_{max} \bullet a / (2 \bullet b \bullet h^2)}$$

where

F_{max} is the maximum load at fracture measured in Newton
a is the distance in millimetres between the upper rollers used to apply the load (the distance between the bottom rollers being adjusted to **2a**)
b width of test specimen in millimetres
h thickness of test specimen in millimetres

It was found that the fracture stresses that could be achieved for both Type A and Type B were sensitive to a number of parameters. The most important of these being:

(a) Viscosity
(b) Filling method
(c) Reinforcement

After optimization of mixing and casting parameters, it was found that bending strengths of around 30MPa could be achieved for the Type A material and bending strengths of around 50MPa could be achieved for the Type B material. As the Type B material is both stronger than the Type A material and can be cured in 48 hours compared to 28 days for the Type A material it was decided that further efforts in the project should concentrate on the Type B material.

Following further optimization tests to improve the repeatability of the specimen casting process a set of 10 test specimens for bend strength were manufactured. These specimens exhibited the bend strengths shown in Table 1 below. The table also shows tensile strengths calculated from the bending strengths by dividing bending strengths by factor of 1.7.

TABLE 1		
Specimen	Bending Strength MPa	Tensile Strength MPa
1	54,5	32,1
2	55,3	32,5
3	54,4	32,0
4	48,5	28,5
5	50,5	39,7
6	54,6	32,1
7	55,6	32,7
8	48,2	28,4
9	48,3	28,4
10	51,7	30,4

As can be seen from Table 1 all specimens exhibited tensile strengths greater than 20MPa which is the tensile stress that a Finite Element Analysis had shown the final end plate had to be capable of withstanding.

Weibull Analysis

The above results were also subjected to a Weibull analysis which is a form of statistical quality control analysis to determine the chances of survival under given circumstances. In the particular case of the rectangular test specimens the Weibull analysis was used to determine the probability that

The Weibull plot for the above tensile results is shown in Figure 2 below together with survivability figures shown in Table 2.

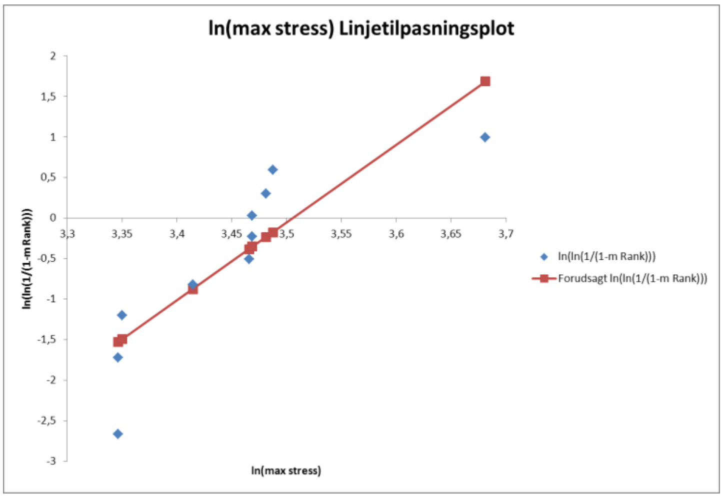

Figure 3, Weilbull plot of the tensile strengths shown in table 1

TABLE 2	
Applied Tensile Stress (MPa)	Probability of withstanding applied stress (%)
39	1
36	10
32	50
26	90
21	99

The Weibull plot is more simply understood by converting the plot into a table showing the probability a test sample would withstand a range of applied tensile stresses. As can be seen in Table 2 if the applied tensile stress is 21MPa or below a test sample has a 99% probability of withstanding the applied load.

WP3 Design Studies

The main task for the endplate is to apply a pressure on the PEM stack while ensuring an even deformation of the stack. It is crucial for the efficiency of the stack to maintain the same distance between the membranes throughout the cell, so the surface on which the membranes are resting should be as flat as possible when the pressure is applied. The deformation of the surface can be no more than 0.2 mm.

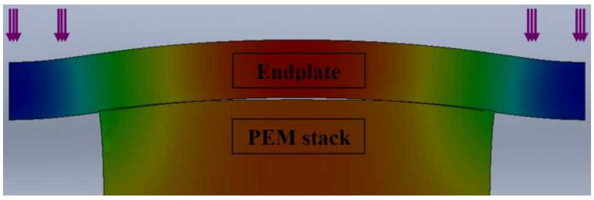

Figure 4. The principle of the problem. When the endplate is bending, so is the PEM stack and the gap between the membranes surfaces is not uniform.

Preliminary analysis

Preliminary analysis showed that it would be difficult to achieve the maximum 0.2 mm deformation, given the fact that the Young's modulus of the injection mouldable fibre reinforced plastic is 50 % of what the composite in current use for the endplates possesses. In order to overcome this problem one opportunity is to increase the height of the endplate, thereby increasing the endplates bending moment of inertia. Unfortunately, it was discovered that this will take up too much room in the endplates surroundings since the height would have to increase substantially above the current designs height of 35 mm.

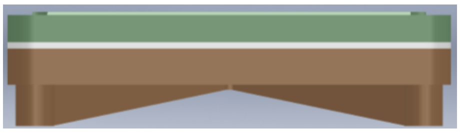

Figure 5. Initial thoughts on the design before the finite element calculations.

Figure 6. Actual height of the endplate was 95 mm when the calculations showed acceptable displacement.

Simplifying the design

At this point it was decided to change the design from the fairly complex tree part model which had to be welded together, to a one piece by rearranging the in- and outlets. This would complicate the arrangement of the pipes feeding the cell, but greatly simplify the endplates.

As mentioned, the problem with the fibre reinforced plastic was the level of displacement. A solution to this problem was to change the geometry of the surface on which the membranes are resting, from flat to having a bulge. When the endplate was pressed into the stack, the bulge would deform into a flat surface. In this way, the strength of the material would be the limiting factor and not the displacement, making it possible to decrease the height of the plate.

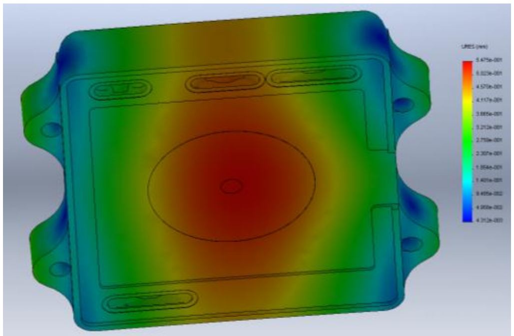

Figure 7. In this design example the displacement is shown. The strategy would be to add the same amount of extra material to the contact surface, facing outward, as the level of displacement, thereby creating a flat surface when loaded.

The major concern with this design was creep. The cell was designed to work at 85° Celsius for 40.000 hours and it was very likely to affect the displacement beyond the acceptable limit. A future hope was to use the same endplates for both the low temperature cells and for the high temperature version working in temperatures up to 180° Celsius.

Using steel bands

IRD had the idea of using two steel bands surrounding the stacks and the endplates instead of the current design using threaded steel rods in each corner. This could be an advantage, trying to reduce the overall weight.

In order to test the implications of this, a simple model was made. The result is shown on the picture below where the contact forces between the steel band and the plate is shown. The force pressing down on the stack is matched by an equal force compressing the top in the horizontal level (x). At the same time, the part of the steel band spanning the endplate is only introducing a moderate pressure on the plate.

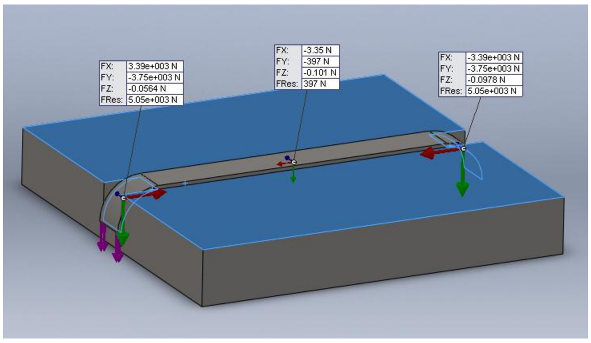

Figure 10 The contact forces between the steel band and the plate

This is a problem since it will not help to decrease the deflection of the plate. For the steel bands to work the idea would need to be combined with a metal plate on top of the endplate to provide stiffness thereby reducing the deformation. This could be combined with the endplate having a slightly convex top which the metal plate would rest upon. When the forces from the steel bands are applied the metal plate would deform the endplate and create the same effect as described above in "*Simplifying the design*". Again the main concern is creep and the long term effect of this.

High strength fibre reinforced concrete

The idea of using a high strength fibre reinforced concrete was introduced. The much higher Young's modulus of the concrete composite means less deflection and its excellent thermal properties would make it suitable for the high temperature application as well. On top of that it does not experience creep at nearly the same level as a polymer and this phenomenon would no longer be a concern.

A challenge was the relatively low tensile strength of concrete composite but this could be solved by using the steel bands. The forces acting to compress the endplate, denoted FX and visualized with red arrows in Figure 4, would help to decrease the tensile stresses in the material. It would also increase the compression stresses, but it was not a problem for concrete composite which has very high compression strength.

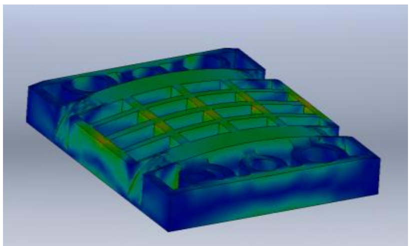

Figure 11. Initial idea in reinforced concrete composite with load applied

The deflection and stresses of different designs was tested using the finite element method and the final design created on basis of these results along with the experiences obtained from test moulding the reinforced concrete. The concrete composite has limitations in flow and the design was simplified from the initial ideas to take this into account.

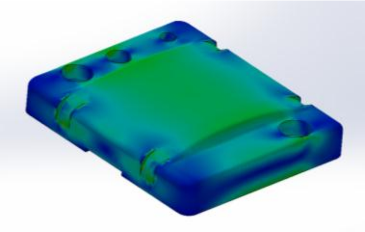

Figure 12. Final design with load applied

The result is a design which is castable in high viscosity reinforced concrete and has homogeneously distributed stresses within the acceptable range when loaded.

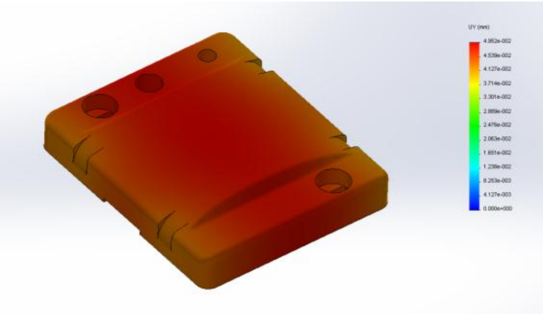

Figure 13. High Young's modulus reduces the deflection to 0.05 mm

WP4 Processing

After considering different approaches to manufacturing the actual end plate it was decide that the best method would be to manufacture a model of the end plate, compensating for the shrinkage the concrete composites undergo when hardening, and then to cast a rubber mould from the model.

The model was machined from POM which is an engineering polymer of high strength and one which can be machined to a smooth surface finish. The model is shown in Figure 14.

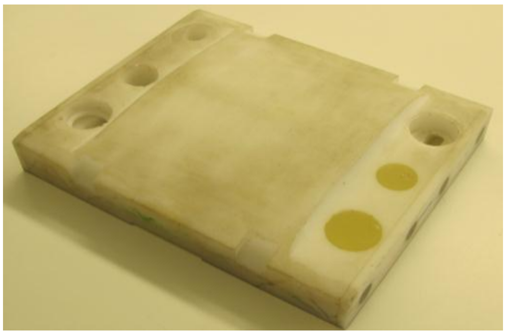

Figure 14. Model used to manufacture casting mould

Mould Manufacture

The next most critical part of the production process was the manufacture of a mould into which the concrete composite could be cast. Two types of hardening polymer were tested in mould manufacture where one of them was found to be too soft for casting concrete composite because, when used as a mould material, it deformed under the weight of the concrete composite. The overall result was that the dimensions of castings manufactured in these moulds would vary from cast to cast. Casting tests using this hardening polymer were therefore discontinued.

In contrast moulds manufactured in the other hardening polymer were much stiffer and did not deform significantly when loaded with concrete composite. A number of two-part moulds were manufactured and used to cast end plates. The major difference between these moulds being the position of the parting line between the two mould halves. It was found that the position and geometry of the parting line played a critical role in the surface quality of the final cast. It was found that if the parting line was incorrectly positioned a form of "cement burr" would be created at the parting line which would require the use of an additional grinding process to remove.

Casting End Plates

Casting end plates involved mounting the hardening polymer moulds in a fixed skeleton to reduce mould deformation during casting. The concrete composite was poured into the mould.

Another major key to success was finding the most suitable point to fill the mould. It was found that an unsuitable filling point would result in some of the defects shown in Figure 15-17.

Figure 15. Endplate with defects from residual air bobles

Figure 16. 4Defect around thread

Figure 17. Endplate with defects around thread and large pores on the top surface

Following the above optimization process which required the manufacture of over twenty end plates it was concluded that filling the mould from a corner was the optimum filling location. Using this location a number of end plates suitable for testing by IRD were manufactured. A typical end plate supplied to IRD is shown in Figure 20.

WP5 Proof of Concept

End Plate Bending Tests

Three point bending tests were also carried out on whole end plates such as the one shown in Figure 19. Unfortunately not enough whole end plates were available to construct a complete Weibull plot and failure-probability table. In addition the endplate top surface is curved and is not well suited to a bending test. However despite these limitations the bending tests that were carried out showed that whole plates tested could withstand maximum bending stresses of over 36-40MPa. It should be noted that these results for bending stress are rather on the conservative side as it was estimated that taking top curvature into account the actual bending stresses were around 20% higher than those indicated by the initial materials tests.

Figure 18. End plate following bending test

Chemical testing

In an attempt to seal the concrete composite surface and thereby limit the diffusion of gasses through the endplate two different coating approaches were tested. Water glass followed by commercial paint, and commercial paint followed by water glass. The tests were carried out on samples measuring approximately 30 cm^3. The objective of the tests was to evaluate the effect of specific reagents which the endplate will be - or potentially could be exposed to.

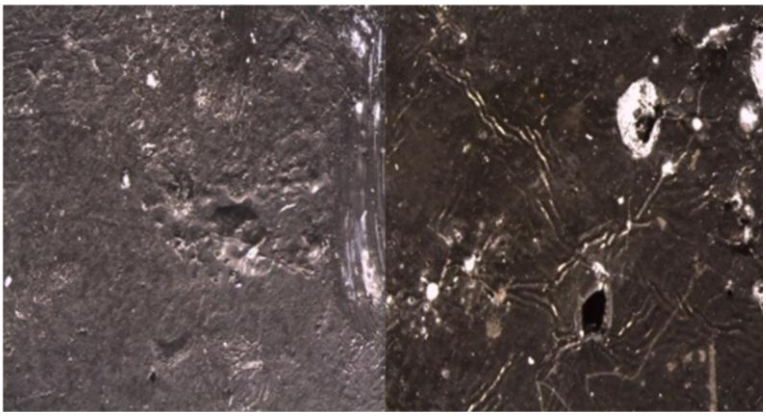

Figure 19. Water glass followed by commercial paint, and commercial paint followed by water glass

Exposure liquids	Water glass foundation Commercial top coat	Commercial foundation Water glass top coat
Reference (DI H_2O)	+1.00g / +1.6%	+1.45g / +1.4%
IRD special mix-ture	+1.57g / +1.8%	+1.11g / + 1.5%
Hydrogen peroxide	+2.43g / +2.5%	+1.80g / +2.4%
Iron(II)sulphate	+0.74g / +0.8%	+1.01g / +1.4%
Formic acid	-2.90g / -3.1%	-3.46g / -4.7%

Table 3. Weight gains associated with exposure (3 weeks) at 80 °C

Since weighing is carried out on a 1 mg incremental weight, a weight difference of 5 mg
is considered significant, although *measurably significant* does not imply that a detrimental change has taken place. As seen in Table 3, formic acid exposure gives rise to weight decrease while all other samples including the reference samples ex-posed to pure water gain weight.

Exposure liquids	Water glass foundation Commercial top coat		Commercial foundation Water glass top coat	
	[Ca], µg /mL	[Mg], µg /mL	[Ca], µg /mL	[Mg], µg /mL
Reference (DI H_2O)	2.9	<0.05	*N/A*	*N/A*
IRD special mixture	17	<0.05	15	<0.05
Hydrogen peroxide	33	0.017	*N/A*	*N/A*
Iron(II)sulphate	450	28	*N/A*	*N/A*
Formic acid	4500	36	*N/A*	*N/A*

Table 4, total concentration of Ca and Mg in exposure liquid after 3 weeks at 80 °C

As seen in Table 4, the acidic liquids are able to extract more of the concrete composite relative to the other exposure liquids. This is expected, and in most cases concentrations are low. The highest observed concentration, [Ca]=4500 µg /mL corresponds in 600 mL to 3 g, which is a significant loss; the IRD special mixture causes much lower losses.

During the corrosion test, all samples exhibited a delamination implying that the coating detached from the concrete composite substrate. The degree of delamination could not be quantified to resolve which is best (water glass followed by commercial paint, or commercial paint followed by water glass). The level of corrosion was attempted quantified using TQIII/ ICP-MS with special focus on Ca and Mg from the concrete composite. The exposure liquids DI water and IRD special mixture cause a low but detectable degradation, as opposed to the exposure liquids consisting of aqueous solution of formic acid, hydrogen peroxide and iron (II) sulphate which cause a more severe degradation.

It could be interesting to employ the methodology on end plates samples *without* coating or coated with a coat that can resist the observed delamination.

WP6 Field Test

The endplates were checked against the dimensional specifications and found to be within the limits. Examination of the threads in the feed troughs showed that they were too rough for obtaining tight connections. Similar conclusion was made after examination of the grooves for the o-rings.
The stack assembly consisted of the following steps:

- Attachment and leak testing of connectors to the plates
- Stacking of current collectors, graphite endplates and PEM cells onto the cathode endplate.
- Placing the anode endplate on top of the cell stack and place the assembly in the hydraulic press.
- Compressing the stack to 10% over the specified clamping pressure

- Checking that the stack have been equal compressed in the 4 corners
- Attaching the steel clamps, tighten them and then releasing the hydraulic pressure
- Checking that the stack have been equal compressed in the 4 corners
- Leak testing the stack

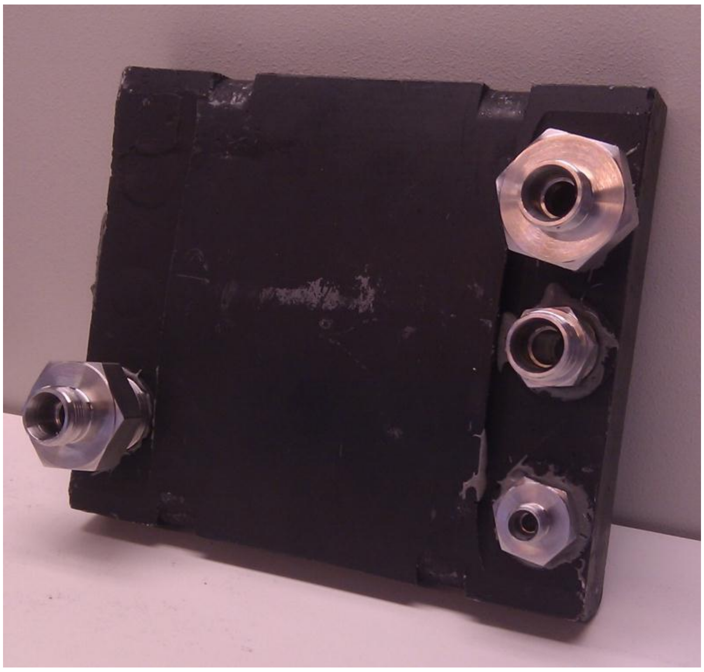

Figure 20. Endplate with connectors

The connectors in the endplates had to be molded into the plates with a sealing adhesion component in order to obtain a tight connection.

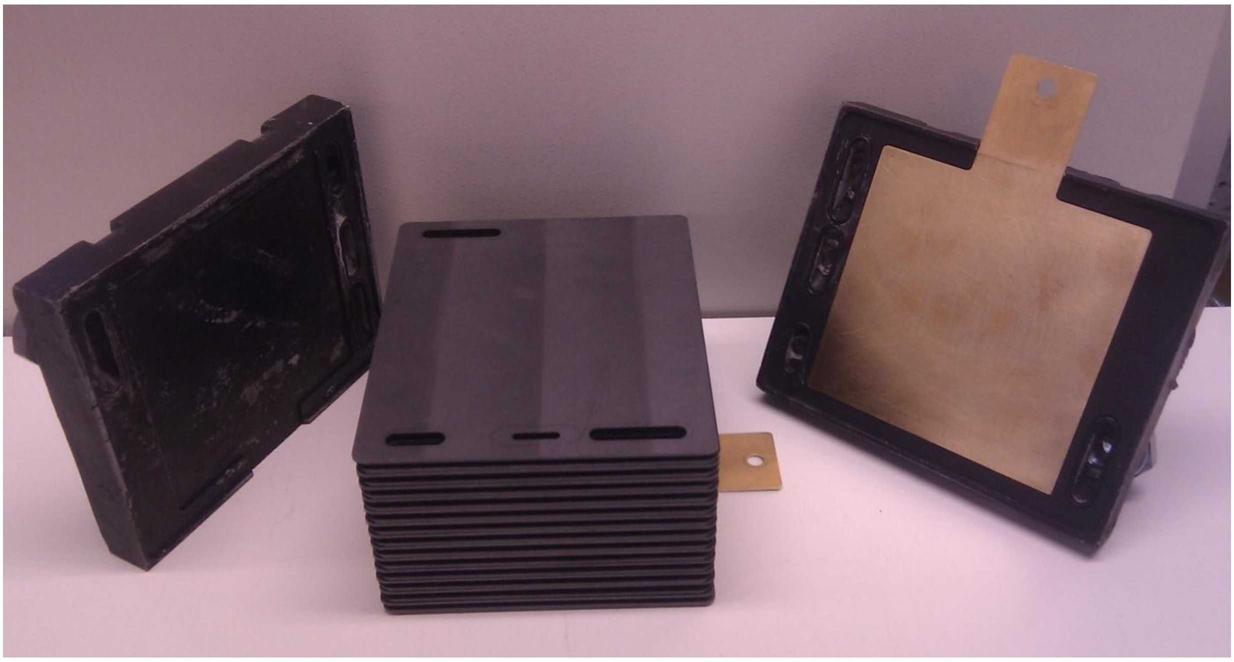

Figure 21. Endplates, current collectors and 12-cell stack ready for assembly.

The assembled PEM fuel cell stack could not pass the leak test procedure. The cells alone had already been tested in another stack with standard endplates and had passed the 3 different leak tests. The tests cover leaks from the anode and from the cathode circuit, leaks between the cooling circuit and the anode/cathode circuit and crossover between the anode and cathode circuit. Leak testing the stack under water confirmed that the leaks were concentrated around the stack endplate/ cell endplate interface, i.e. the o-ring sealing. Disassembling the stack and cleaning the o-ring grooves and all similar attempts to improve the tightness did not really help. The o-ring grooves were simply too rough to make a tight sealing. However the leakages were to the outside why the stack could be tested as long as it was placed in area with sufficient exhaust to remove the hydrogen leaking out of the stack.

Stack testing

The assembled LT-PEM stack with the molded concrete composite endplates was placed on the test bench and connected to the hydrogen supply, to the 100% humidified air supply and to the thermostated cooling water supply.

The stack was heated to 68 – 70 ^{o}C through the cooling circuit and tested for a full test period of 4 hours of continued operation under standard conditions at ambient pressure and 0.3 A/cm^2.

Figure 22. The LT-PEM stack with concrete composite endplates and steel clamps.

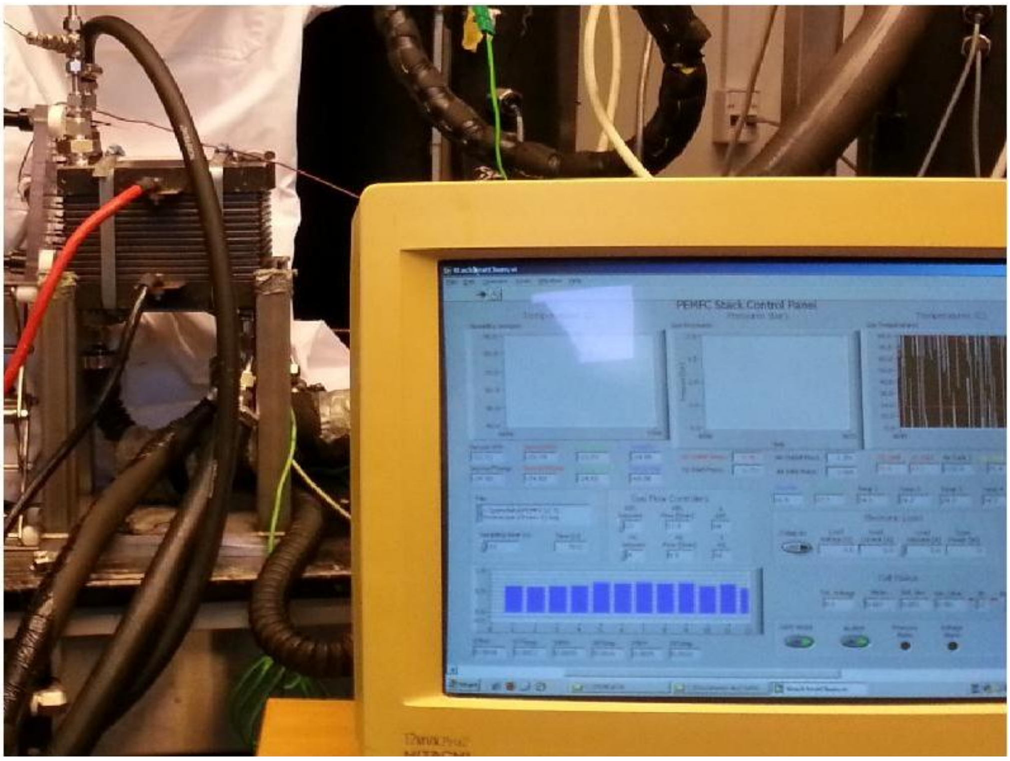

Figure 23. Stack on the test bench. The 12 cell voltages are displayed on the screen.

The stack and the endplates were examined before, under and after the test and the following were observed:

- No observable bending of end plates
- End plate connections were tight
- The O-ring sealing between end plates and flow plates were leaking
- Stack operated stable during the full testing period
- No degradation of endplates could be observed

It was concluded that the performance of the end plate fulfill the required specifications except the o-ring leakage and that the end plates therefore can be used when sealing grooves have been improved.

WP 7 Exploitation

Comparing the specifications with the properties of the new end plate shows that the only specification which has not or will not be fulfilled is the weight specification. The specification tells the weight of the plate must be 1 kg or lower. The present used glass fiber reinforced endplate has a weight of 2.1 kg. The new concrete composite based end plate 0f 1.8 kg.

The plate cost specification is 50 DKK/plate at a number of 5.000 pieces produced. The raw material cost for the new plates is estimated to 30 – 35 DKK /plate and the cost price for manufacturing one plate is estimated to be around 250 – 300 kr. Based

on analysis of the different steps in the molding process together with the raw material price is it estimated that a cost in the range 50 – 100 DKK/plate can be reached. The other plate specifications are either fulfilled or are expected to be fulfilled after further development.
The new endplate construction, manufacturing process and cost potential are all in all so attractive that that it must be exploited:

Figure 24. Overall development steps to a production of endplates.

The manufacturing process for the endplates has to be further developed in order to solve the identified problems with leakage etc. At the same time the molding process will be optimized. This may be accomplished in a development project involving TI, IRD and possibly a company having a molding based production.

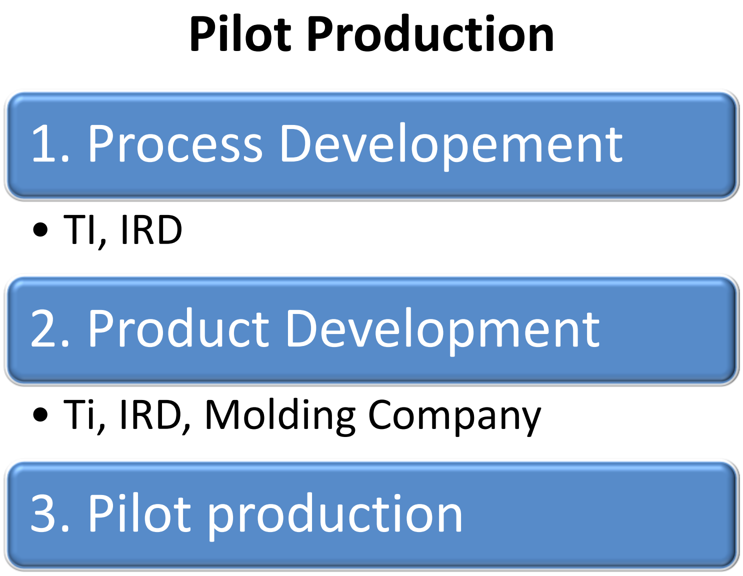

Figure 25. Suggested future outlook for PEM low cost endplates

IRD plans to market the endplates for PEM fuel cell producers, as the production process matures. The product will be a valuable addition the on-going business within PEM fuel cell components (e.g. flow plates), – stacks and – power products. Pilot production is presently a strategic focus area for DTI and thus the institute plans to initiate development of pilot production of the endplates. The production will be sold or licenced to a third party company, as the demand for fuel cell components takes off and as the pilot fabrication reaches production level.

Conclusion

PEM fuel cells endplates of high strength concrete composites has been developed and tested. The concrete composite could be used to manufacture end plates to within the geometrical tolerances required and with strengths that can withstand the service loads. The developed endplate tolerate the temperatures end plates are normally required to withstand. The developed solution is significantly cheaper than the high strength glass fibre reinforced epoxies presently used for end plate manufacture. The field test was in many aspects successful; However, the gas sealing can be further improved. The weight may still be an issue for some applications, even though it is lower than the endplate currently used. The weight issue can be addressed in a future project.

The work has resulted in a new endplate design, which makes the stack assembly simpler and with fewer components. The endplates fabrication involves low cost routs, which can be scaled up as demand of fuel cells takes off.