CONCRETE CANOES - HOW DO THEY DO IT?

CONSTRUCTION REPORT 2012 –PART 1

Enschede, April 2012

BetonBrouwers
Study Association ConcepT
School of Civil Engineering - University of Twente

Preface

Preceding on what is coming we want to outline the work that has been shifted by the BetonBrouwers[1] and everyone that bears a warm heart towards BetonBrouwen. The concrete canoe challenges in Arras (FR) and Zwolle (NL) are approaching rapidly, meaning that again a year of hard work has passed. And how....

Based on our experiences from previous seasons new plans were made for season 2012. Although race canoes are our core business and something we have proved to be pretty good in, we decided to use our knowledge and experience from previous seasons to explore different applications as well. Meaning that for this season we also had a look at durability and innovation. Eventually we made a concrete canoe out of recycled concrete canoes from previous years and we constructed a concrete canoe that can be folded into a compact package. Concerning the race canoes the focus went to the development of a better (lighter) concrete mixture and the aesthetics of the canoes by integrate concrete decorations into the hull.

Eventually all the work resulted in six new concrete canoes. With our new canoes we will participate in the French competition for the first time in the history of the BetonBrouwers and for the sixth time in the Dutch Concrete Canoe Challenge (BKR). And despite our dominance during the Dutch and German competitions last year, season 2012 will still be a tense season since we don't know what our competitors did during the last year. So, were other students enjoyed their spare time, the BetonBrouwers worked hard to develop new canoes, develop new concrete mixtures, construct six magnificent canoes and train their paddling skills in order to beat the competition for the fifth year in a row.

Finally we want to use this occasion to thank the people who have supported us during this project and bear a warm heart towards concrete canoeing. First we want to thank everybody assisting the BetonBrouwers with the construction of the canoes, without their assistance it would be impossible to build the canoes. Second we want to thank all the people and companies that have supported us to achieve our goal of build beautiful new concrete canoes. Last but not least we want to thank the people from Euros Kano for providing us with the right training facilities.

Remains us nothing else than wishing the reader a lot of pleasure with reading this report.

BetonBrouwers 2012,

Ynze Goinga	(Chairman)
Cindy Clevers	(Vice-Chairman)
Simon Janssen	(Secretary)
Rik Goossens	(Treasurer & Event manager)
Anna Steiner	(Public Relations)
Chiel de Wit	(Head of Design & Public Relations)
Casper Rood	(Chief construction site)
Frank Aarns	(Manager)
Sander de Waard	(General Member)

[1] Translated: ConcreteBrewers

Table of Content

Introduction

In front of you lays the construction report of the construction committee 2012 of Study Association ConcepT. Since July 2011 this committee, consisting of ten ‘BetonBrouwers’, has put a lot of dedication and effort in designing and constructing five magnificent concrete race canoes and also for the first time a significant different, innovative, canoe. This report has been written in order to give the construction jury a clear insight in the applied design and construction as well as its implementation. Besides it gives the sponsors and other interested people an impression of the way our concrete canoes are build. Furthermore this report serves as documentation for future members of the committee.

The phenomenon Concrete Canoe Challenge can be found in many countries in Europe and abroad. This year will become a special year for us because besides that we participate in the Dutch competition we will participate in the French competition. In the Netherlands the Concrete Canoe Challenge (BetonKanoRace) is organized annually under the auspices of the Dutch concrete association (Betonvereniging). And after years of absence the University of Duoai initiated the organisation of the French challenge: the Challenge Canoë Béton. During the events students from different academies, universities and other institutions compete in their self-build concrete canoes for the honour. The aim of these fantastic events is to promote the multi-purpose product CONCRETE. This year the competitions take place in Arras (France) and Zwolle (Netherlands) where we will try to beat our competitors and conquer the first price!

In this report the focus is on our race canoes, which our core business and something we have proved to be pretty good in. After the successful side project of the lightest canoe (new record) in 2011 we decided for this season to use our knowledge and experience from previous seasons to explore other applications as well. Meaning that for this season we also had a look at durability and innovation. Eventually we made a concrete canoe out of recycled concrete canoes from previous years and we constructed a concrete canoe that can be folded into a compact package. These developments are in particular for the Dutch competition and are not mentioned in this part of the construction report, more about these developments can be found in ‘Durable Innovation with concrete – Construction Report 2012 - Part 2’.

To construct successful concrete race canoes, three essential elements are required. The first element is a motivated, well trained and well supported team. The second element is a optimal hydraulic design. The third element is a perfect concrete mixture. These elements form the three pillars to become successful in Concrete Canoeing and are described in the first three parts of this report. The first part covers the history of our fantastic team, it’s team members and the supporting companies. The second part concerns the design of the canoe, starting with the principles it’s based on followed by a mechanical analysis. In the third part the material concrete is explored. First the theoretical background is discussed after which the concrete mixtures are composed and analysed. In addition to the first three parts, the fourth part of the report describes the process behind the construction of the race canoes of season 2012. The report is completed by a concluding chapter and an overview of the consulted literature.

Besides the information in this construction report, more information about our team, our activities, our achievements and pictures & video’s can be found on our website: www.betonbrouwers.utwente.nl.

Part 1

BetonBrouwers – An honour to be part of

Success in concrete canoeing is based on three pillars. The first pillar is a solid team. Since 2007 the BetonBrouwers form the construction committee of Study Association ConcepT of the school Civil Engineering at the University of Twente. Only the real diehard Civil Engineering students with a heart of concrete, loads of motivation and a lot of persistence can become a BetonBrouwer. Before one is allowed to call himself a BetonBrouwer, he or she really has to earn it! That is why it's a real honour to be part of this committee! In this chapter we provide some background information about our committee: it's history, members and the supporting companies.

1.1 History in the Making

It all started in 2007 with a group of four students which were experimenting with fibre reinforced concrete. This project made them realise how much fame can be gained with brewing concrete. Thereby it made them clear that this fame was only achievable with blood, sweat and tears. Then dhr. Verhagen came on our path, making us enthusiastic about pre-stressed concrete. Unfortunately there were no bottles of champagne that could be deserved with experimenting with pre-stressed concrete. But on the other hand it was much better applicable in canoes, were it was about after all….

2007: Rising from the ashes

In the year 2006, Study Association ConcepT was asked by the Dutch concrete federation to organize the 30th Dutch concrete canoe challenge. Because of the 30th anniversary of this yearly race, the event in Twente had to become special and bigger than ever. A special guest was invited: the champions of the American Concrete Canoe Challenge!

To give this American team a challenge, four diehard students Civil Engineering joined forces in March 2007 to form the new construction committee of ConcepT. They called themselves the ‘BetonBrouwers’ (ConcreteBrewers). They soon concluded that the old canoe mould, at that time used for about six or seven years, had to be replaced by a new one. In combination with the mould a new construction method and concrete mixture were developed. So after months of hard work, the job was finished. In the second weekend of September 2007 three splendid canoes were shining in the Dutch evening sun. Like a phoenix rising from the ashes, the concrete canoes from Twente would turn out to be a threat to every team.

On the foggy morning of the 8th of September the races started. Although it wasn’t possible to test the concrete canoes before the race, training effort in the months before with regular canoes paid off. It proofed that the canoes from Twente did a very good job. In direct battles, canoe ‘Voortvarend’ managed to beat seven canoes on the sprint. In the sprinting races, canoeists Frank Aarns and Sevrien Ferrée managed to qualify themselves for the final run. Their competitor being the Americans from Madison Wisconsin: David against Goliath. After a thrilling race the Americans won, though it was only by a minimum of two seconds.

During the 400 meter curvy trail, the men final was again the domain of the Americans and the Dutch heroes from Twente. This time the University of Wisconsin was a competitor of another class and the Yanks won again. The story of success of the two second place prices were widely spread during the weeks that lied after. The BetonBrouwers were determined to put everything up for the next edition of the concrete canoe challenge, which was to be held in May 2008 in Delft. The story continuous...

2008: We came, we saw, we kicked ass!

After being successful on the concrete canoe challenge of 2007, the BetonBrouwers agreed that this story of success had to be continued. Together with the board of ConcepT it was decided to make the construction committee a continuous committee, resulting in less loss of knowledge. The core activity would be designing and building concrete canoes, something in which we were getting very good at. After attracting some new team members, the BetonBrouwers started to work on the new season.

For all the work we had on making the mould the year before, we decided that for 2008 the mould of 2007 was to be used again. Better concrete, a slightly different method of building canoes and making the canoes as thin as possible were the key aspects of making better canoes than the year before. Besides that, pigments were used instead of paint to colour the canoes. The road to Delft 2008 wasn’t as easy as we thought though. Making the first of three new canoes took us two full days. Though, we managed to build three canoes again.

The three boats were named: Veni, Vidi and Vici. These famous words of Roman Julius Caesar (I came, I saw and I conquered) would turn out to describe our canoe challenge experiences in Delft pretty well.

On the rainy morning of 17 May 2008 hell was unleashed on the waters near Delft. On the water of the 'Delfste Hout' it all had to be done; it was the day of truth. Frank and Sevrien, the top canoeist of Twente, made it to the finals at the 200 meter sprint. The teams in the other divisions, mixed and ladies, were less fortunate. A French team from Le Bourges was considered to be our only competitor. Because the 200m final was sabotaged by another team, the French won the race.

Thanks to a great lunch, arranged by our sponsor, we regained strength in our muscles and minds. We now totally focused on the 400 meter races. Besides our men, the ladies performed very well on the 400 meter distance. They made it to the finals and actually won the race. But the ladies turned counter clockwise at the buoy and were disqualified. In the semi-finals, the men showed that they could beat the French and in the final they did it again. Victory was ours! Because the jury was very pleased with our canoes and our result on the tournament, they decided to call ConcepT the overall winner of the Concrete Canoe Challenge 2009. Our goals were achieved and the success was complete. We came, we saw and we kicked ass!

2009: Conquering Europe
After the Concrete canoe challenge of 2008, the BetonBrouwers were officially Dutch champion. Though we wanted even more; not only a good reputation in Holland but also abroad. Participate at the German BetonKanu-Regatta, which was to be held in Essen on the 19th and 20th June 2009, became the new challenge of 2009. Besides that, we had to protect our title at the Dutch concrete canoe challenge in Roermond.

This year, we were up to another new challenge: a new canoe design. Using experiences from the past years, the new design was based on speed and manoeuvrability. After constructing a 1:1 wooden model of the new canoe design, we succeeded to make a nice polyester mould. Constructing the canoes was succeeded without any large problems. A new orange lightweight concrete mixture with a perfect workability resulted in a smooth construction process. The concrete combined with synthetic meshes and steel cables as reinforcement turned out to be a perfect combination. This made it possible to make walls of just 5mm thick which were still flexible and strong enough to withstand some impacts. The nice orange canoes were finished with nice and catchy names and the steel cables in the top of the canoes were put under tension. We were ready to rock 'n roll on the water!

On Friday the 5th of June, the transport of three nearly 6m long orange canoes to Roermond left Enschede. The next morning the races began. During the short distance (200 meter) our experienced canoe team, Frank and Sevrien, proved again to be best of the best. Without any problems, they reached the final round and won it with ease. Though, they were not the only ones to race with success. Our mixed and lady teams showed that they could paddle as well. This resulted in several prices, including one

first price at the mixed teams. Also the long distance over 400 meters became the winning area of the BetonBrouwers. At the end of the day, 13 prices could be taken back to Enschede. The BetonBrouwers ruled the BetonKanoRace 2009! The results were devastating.

Two weeks later, we drove to Essen (D). The biggest challenge was yet to be come: participating in the German BetonKanu-Regatta. The first day was assigned to show the canoes to the different jury's and other interested people. Most of the eastern neighbours were sceptical about our design: we might win on the straight, but a canoe of nearly 6m long could never make the turns. Well, we proved them wrong that afternoon by giving a little demonstration, the shock was complete.

The next morning the races began early to make sure all of the canoes could sprint for the finish. During the qualification rounds, it was clear that our success in Holland was not exclusive; every canoe in the German races fought themselves to the final rounds. Unfortunately, two of the men teams were not good enough to go beyond the quarter finals. Frank and Sevrien however won every (final) round with ease and were the first couple to qualify for the final. Also two ladies managed to paddle themselves to their final. Unfortunately the ladies weren't able to paddle themselves to one of the first three places and finished fourth. Still a very good result!

After the ladies final, the waiting started for the men final. Although starting with a lot of confidence, the Dutch felt the pressure. The lighting start of Frank and Sevrien was again determining the course of the race. The two top canoeists from Twente eventually won the final overwhelming. Our success was complete and was rewarded with a very nice first price.

Because of the success in Germany, the BetonBrouwers got a lot of attention both at the University, in the region of Twente and nationwide in the Netherlands. Some new members were attracted to reinforce the team for the upcoming season.

2010: Scoring three hattricks

After the succesfull season of 2009, the start of the new study season in September was used to start on a new BetonBrouwers season as well. Now we had the confirmation that the design of the canoes was almost perfect, the BetonBrouwers decided to put effort in making the canoes even nicer, smoother and lighter by using all kinds of different concrete mixtures.

While our 'cornerstones' Frank and Chiel were studying civil engineering aspects abroad (Trondheim, Norway resp. Prague, Chzech Republik) the committee slowly worked to the new canoes. In the first weeks of 2010 our main sponsor ENCI was visited to gain some insights in the new concrete mixtures which were going to be used in the new canoes. Remarkable was that marble was to be 'in the mix' of one canoe: polishing that boat would make the canoe shine like a star.

The mould from the previous year was refurbished and a car paint shop put a nice and smooth new layer of paint on the mould. From this point the canoes could be constructed. Almost every week a canoe rolled of the assembly line. Trainings were hard as ever and also canoeists from ConcepT had to put a lot of effort in paddling to work themselves through the training. On the eve of Thursday the 3rd of June the BetonBrouwers were ready to rock again!

On the sunny morning of Friday the 4th of June the delegation from Twente searched their way to Utrecht. A camp site on the outskirts of Utrecht was used as base for the coming weekend. With a large army tent the BetonBrouwers base wasn't to be overseen. During the examination of the canoes by the jury the canoes, the BetonBrouwers gained respect with the work they had done. The white canoes were the center of interest. The day was closed with a canoe trip over the town canals of Utrecht, the draw for the races of the next day and a party from hell with singing hero 'Starkoo'.

The following day the races began early. Starting slowly, the races in the men and female disciplines were dominated by the white canoes from Twente. In the mixed raced the competition was fierce, though one duo was able to reach the semi-finals. In the men competition, our 'canoe legends' Frank and Sevrien did what they had to do: winning every race in de 200m an 400m sprint races. Even athletes from Prague weren't able to stop the two. Also Casper and Chiel were able to reach the final, though only the 200m one. In de semi finals for the 400m their canoe was deliberatly crushed by the Czechs, which weren't going to win the fair-play cup.

At the female competitions Nienke and Floor resp. Cindy and Leonie reached the final of the 400m. Both lady teams showed what they could and won the first and second price during the final run in the centre of Utrecht! Frank and Sevrien won the 200m and 400m (third year in a row = hattrick one) sprints overwhelming, while Chiel and Casper did a good job by winning the bronze medal on the 200m. While the construction of the canoes from Twente was again not to be outclassed by other teams, the second hattrick came in sight and the construction price was won. The third hattrick was winning the overall-price.

The performance of the BetonBrouwers was unique. Never in the history of the Dutch Concrete Canoe Challenge one team managed to win the overall price three years on a row.

2011: Going south and eastbound

After the successful year 2010, the BetonBrouwers were determined to go on with their well performing concrete canoes. Though for 2011 the level was set to be even higher than the years before. Gaining the price for the lightest canoe was one of the goals for 2011, as well as searching for a way to build lighter racing canoes; engineering on the edge. Because of returning to Germany again, the 2011 canoes had to carry something 'Dutch'. Therefore the BetonBrouwers decides to build red-white-blue colored canoes: the colors of the Dutch flag.

After a successful designing, building and training period, a fully stuffed van and a six meter trailer left Enschede on the 20th of May 2011. With five canoes the team from Twente was heading south, destination: Eindhoven. On the way, the new BetonBrouwers accommodation, a big Army tent, was picked up which was immediately set up after reaching the camping ground in Eindhoven. After screening by the jury, the canoes were prepared for the races the day after. Although the design of the canoes was perfect, the thinness of the canoes was set to be the Achilles heel, as turned out the next day.

Under blue skies and high temperatures, the races started on Saturday morning. The qualifying rounds went very well for all of the red, white and blue canoes from Twente. Though, during the next rounds the canoes

proved to be constructed too light: they just weren't suitable for the big forces applied on the canoes. Because of that: one canoe sank during the races, one collapsed after a race and one race canoe was held together by lots of duck tape. A little success however was the lightest canoe, which weighted only 11 kg! It was a new Dutch national record. It took about ten minutes to paddle 100 meter, but the BetonBrouwers crew managed to get the canoe over de finish line!

Despite all the broken canoes, the BetonBrouwers performed well in the finals. At the end no less than fifteen prices were gained. Among those several first, second and third prices for the races, the construction price, lightest canoe and off course the overall price which was won by the BetonBrouwers for the fourth time in a row.

After the successful weekend in Eindhoven, the BetonBrouwers couldn't lay back because of the fact that two new canoes had to be constructed for the concrete canoe races in Magdeburg (D), which were to be held at the end of June. The new canoes were build with more mesh and more concrete than the canoes constructed for Eindhoven. It seemed that the BetonBrouwers had reached the limits of reducing the weight of their canoes.

The race started on Saturday the 25th. Luckily the BetonBrouwer crew and the canoes arrived in Magdeburg safe, so nothing could withstand a wonderful race. This year, Frank and Sevrien had to defend their title. Besides that, Peter and Casper as well as Cindy and Leonie were two teams the rest of the competitors had to be beware of. The training the three Dutch couples followed the previous months, turned out to be working well. Without any troubles, both the two men and women couples reached the finals! This meant that Frank and Sevrien had to paddle against Peter and Casper, as well as two German teams. Cindy and Leonie started as favorites in the finales, and they turned out to be real champions. With a smashing races they overruled the other teams completely and won the final with a superior lead. It was the first time, the BetonBrouwers' ladies won the German competition.

A few minutes later, the men final with our two couples started. The German team from Chemnitz had a lighting start, with Frank and Sevrien and Peter and Casper following towards the turning buoy. Though the team from Chemnitz wasn't able to turn well: the Dutchies used their superior turning techniques and were able to pass Chemnitz. Frank and Sevrien headed out towards their second first price in the German competition, Peter and Casper were eventually passed again by the Germans and finished third. A very good result! The BetonBrouwers took the double in Magdeburg!

Now the arrows are pointed towards the season of 2012: France and Netherlands again. After a whole year of training and building new canoes, the team from Twente is completely ready to take on other competitors.

1.2 Team members

As construction committee we strive to be a continuous committee which consists of a diversity of students, meaning students from different phases of the study Civil Engineering. In this way we try to pass the knowledge to the younger members instead of inventing the wheel over and over again. In this paragraph all members of the BetonBrouwers are introduced, giving an insight in their backgrounds and their functioning within the committee.

1.2.1 Ynze Goinga alias 'Johan'

BetonBrouwer since season 2011
Current function: Chairman

On the stormy day of 20 December 1986, the Fries' town of Leeuwarden was startled by the birth of Ynze Goinga. After having an interesting youth in the little town of Lippenhuizen (near Gorredijk, Friesland), he didn't know what to do after his years on the secondary school. That's why this sober Fries decided to undertake a complete foot trip to China! Only crazy people think about walking to Beijing, but Ynze really did it. Visiting nice and picturesque countries as Israel, Libanon and Iran. Even Afghanistan was crossed. Though there came a time that our 'Afghan warrior' had to choose for his future.

Because Ynze didn't like Delft (and he's right!) he decided to choose for the best option: studying Civil Engineering at the University of Twente in Enschede. In Twente Ynze became notorious as 'Johan' of 'Josef'. As the responsible board member for the Betonbrouwers, Ynze was triggered by the success and sociable atmosphere of this concrete canoe team. He therefore paddled a few heats with 'the Slachttand' in the concrete canoe challenge of 2010 in Utrecht. Although this canoe weight almost 100 kg, Ynze made it, together with Laura, to the finals 400 meter mixed. Ynze decided, already as board member, that he had not yet reached the summit of his capabilities. That's why the BetonBrouwers could welcome Ynze as a new member in January 2011. Within the last few months Ynze proved he is a good catch for the BetonBrouwers. He keeps the atmosphere relaxed and goes along with everything. Ynze claims that he has helped constructing every single concrete canoe of the last two years and he is determined to keep this record. After a day of construction he likes to drink a nice cold beer, that's why he also joined the bubble commission. But the best characteristic of Ynze is his well developed taste for woman, although that doesn't always result in a good score.

1.2.2 Cindy Clevers alias 'Cindieeee'

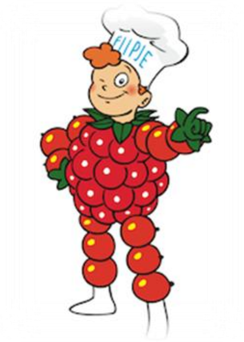
BetonBrouwer since season 2011
Current function: Vice-chairman

Since Cindy is the first female BetonBrouwer, the moment that Cindy became a part of the BetonBrouwers became a historical moment in the already rich history of the committee. With her good looks she makes many concrete hearts beat faster. Hopefully this will have a positive influence on the performance on the guys in the team. A positive effect or not it's for sure that Cindy is determined to make season 2012 a big success.

Despite her fanaticism and persistence there is one thing that worries the other BetonBrouwers. Cindy and concrete canoes don't seem to like each other. Maybe her father, who works in the cement industry, forgot to learn Cindy that concrete can be fragile in some circumstances since she sunk a canoe during her Kick-In period. Despite her first experience with a concrete canoe resulted in a wet suit it luckily didn't stop her, since in the past two years Cindy has shown to be a very talented concrete canoeist.

With her winner mentality she fits perfectly within the team. Thereby she is a fanatic racing cyclist, her love for cycling results in such a perfect physical condition that even a mountain pass in the Italian Dolomites is no challenge for our Cindy. But since this year Cindy has a new passion; playing soccer! Her condition in combination with some training on the water would make Cindy a feared opponent because no matter if she is racing on a bike or paddling a canoe, when racing, Cindy gives all she's got!

1.2.3 Simon alias 'Flipke'



BetonBrouwer since season 2012
Current function: secretary

Simon became a BetonBrouwer in the year 2011, the most successful year in the history of the BetonBrouwers. Partly because of this success he decided to become part of the "Betonnen Bikkels" of ConcepT. Simon was raised in Tiel (Gelderland) and has a typical "Brabants" accent, probably because Gelderland is to close Brabant. This weird accent prevents him from talking Dutch in a decent way.

Since the first day he joined the group, Simon surprised us all. While he was just looking around and hearing us talking about certain topics, he directly called Yorick a passive member. Because this is a bold thing to say for a rookie the BetonBrouwers we are looking forward to see if he can back this up with a very active attitude. We are very sceptical, because his whole appearance is very sluggish.

Simon seems to have contacts all around the country, because his dad makes fake concrete with polyester. Simon is trying to use the relations of his dad to apply it to make real concrete. We can't wait for all the special types of concrete he is going to design (as long as it's real concrete)!

1.2.4 Rik Goossens alias 'Fry king Rik'

BetonBrouwer since season 2009
Current function: Treasurer & Event Manager

Our very own 'fry king' was born in the city of Arnhem, but still manages to be a jolly fellow. Proud of his heritage and full of love for the game of football, he's a devoted supporter of Vitesse (sadly not a particularly good team in the Dutch Eredivisie, but they try to become champion in 2013). As Event Manager, Rik makes sure every detail about our being at the races is as it should be. He is the one that is always in contact with the BKR organization about things that are not sure or still have to be done. He also makes a great deal about the team structure during the races, making sure that everything goes as smoothly as possible.

Rik isn't the best constructor on the team, but provides something way more important: his famous minced-meat hot dogs, frikadellen. This is actually how he got the name "Fry King Rik". Rik keeps the team nourished during the long hours of development and construction of the canoes. He also makes sure that there always is a fresh box of beer to celebrate the birth of yet another canoe! By doing this, Rik keeps the team hard-working and happy during construction. Nothings speeds up a building process more than the prospect of a cold Grolsch Beer accompanied by Rik's famous minced-meat hot dogs!

In short: Rik has one of the most important roles in our team. He motivates the others to always give their best effort!

1.2.5 Anna Steiner alias 'Einsteiner'

BetonBrouwer since season 2012
Current function: Public Relations (financial)

For the first time in the history of the BetonBrouwers, we adopted foreign students in our committee. One of them is Anna Steiner, charmed by the BetonBrouwers since her participation at the BKR Eindhoven. At the first meeting she may seem a sweet, little and innocent girl, but we can advise: do not make Anna angry: you won't survive that. Anna is namely a pure winner.

This season Anna is responsible for the financial public relations this season. With her German roots she can benefit from the publicity of the BetonBrouwers in her home country. And maybe she can increase the famousness even more.

As said, Anna is a born winner and absolutely can't stand losing. That is visible at the football field: at first she made the transfer from TV Dinklage to vv Drienerlo. As a solid defender in Ladies 1 she is the fear of all strikers. Besides that, she likes to win the third half too. Anna's aim is to achieve the same in our concrete canoe team, and especially wants to beat her compatriots in 2013!

1.2.6 Chiel de Wit alias 'Guus'

BetonBrouwer since season 2009
Current function: Public Relations (materials) and Head of Design

It is said that Chiel sleeps with a concrete bible besides his bed and that concrete is running through his veins. If it's true nobody knows, what we do know is that Chiel is fanatic about concrete and its applications. This passion for the material and his practical insight make him a perfect member of the BetonBrouwers. After being the chairmen for a while Chiel decide it was time for somebody else to take over the stick and he started working as PR-materials. Beside this job he was responsible for making an even better concrete mixture then the previous years.

Beside working hard for the BetonBrouwers Chiel has some more passions. One of these is playing soccer. Chiel is an fanatic player and plays for multiple teams. Most times he plays as a defender and his favourite position is left back. On the pitch Chiel is a hard worker and feared by many opponents, something he also tried to achieve with concrete canoeing. But unfortunately Guus is no 'Guus geluk' when it comes to concrete canoeing, on the contrary. During the BKR in Eindhoven his canoe even sunk, let's just say it could not cope the brute forces ;-).

Besides an interest in concrete, Chiel is also interest in foreign cultures. For half a year he went to Prague, to study he said. We think he just wanted to learn more about the country with the biggest beer consumption of Europe and the inventors of Pilsner. Somehow it also brought him in contact with the French culture for a short period, but we can happily announce that at the moment it is all about burritos and sombrero's.

1.2.7 Casper Rood alias 'The Blister'

BetonBrouwer since season 2010
Current function: Chief construction site

In November 1987 Casper was born in the most beautiful town of Limmen, a small town with approximately 7000 inhabitants. In 2006 Casper moved to Enschede, to study Civil Engineering, which was highly appreciated by the inhabitants of Limmen. Sadly enough for them he returns weekly to drive a forklift for work.

Luckily the people of Enschede did like Casper, and in 2009 he decided to enter the BetonBrouwers when he finished his year on the board of the Study Association of ConcepT. Casper is of great value to the BetonBrouwers, with his hard working mentality if he manages to finally start doing something. Nowadays, Casper is the manager of our workplace, where he tries to see where everyone puts the equipment and to put it in the right place. Casper can be really serious if it's necessary, and he is putting all his effort in arranging the perfect facilities for casting our concrete canoes.

Casper is training hard for the Concrete canoe race, where he tries to beat everyone. Time will tell if his anger to win will result in the first place. This are the kind of people the BetonBrouwers need to make sure that this year's title again is claimed by the BetonBrouwers. To sum up: Casper can be seen as our cheerful, motivated and knowledgeable, but particular cheerful team member and with him the BKR 2012 will come to a good end.

1.2.8 Frank Aarns alias 'Prof. Arms'

BetonBrouwer since season 2007
Current function: Manager

On the 27th of December 1985 a bright star in heaven wasn't guiding three kings to the promised land, but towards the city of Nijmegen: the birth of the young miracle Frank Aarns was a fact. His sporting capabilities became evident when he swam the Waal river towards the small village of Elst, where he grew up and his interest in Civil Engineering rose.

During his years in Twente, it was clear that Frank wanted to do some more than just study. Together with fellow students he was one of the founders of the BetonBrouwers and became chairman a study tour towards South Africa. Besides that, in a possible Third World War situation, Frank will put his life in line for our beautiful country as a 'Saturday and Sunday' soldier of the National Reserves of the Royal Dutch Army.

Though that was not yet the summit for this blond 'womanizer'. In 2010 Frank was selected to perform the role of Technical Project Leader in the Solar Team Twente. Although nothing is so interesting and challenging as building concrete canoes, Professor Arms decided to construct a solar car to compete with other teams in the famous World Solar Challenge in Australia in October 2011. Although Frank knows from concrete canoeing experiences how to deal with teams as from other universities, he did not manage, together with his team, to beat the competition 'down under'.

2012 will be the last year of Frank's career as a BetonBrouwer. Together with another concrete canoe legend, Sevrien, Frank was unbeatable on the water from 2008 to 2011. Frank's name will have a prominent name on ConcepT's 'wall of fame' and will be remembered forever as one of the most dedicated to concrete canoeing in the history of this study association.

1.2.9 Sander de Waard alias 'Daffy'

BetonBrouwer since season 2012
Current function: general member

During a cold and windy blue Monday in January there was a lighting bold in the sky. Because it wasn't a star it didn't attract the Sheppard but the result was almost just as stunning, because there was Sander. During his year as a board member of ConcepT (he was responsible for internal affairs) he build/demolished everything on his path. As a miracle he wasn't responsible for the BetonBrouwers, but still he was involved in most of their construction work. During the races he decided that drinking beer was just as important as peddling.

Now the time has come to rise, so Sander decided to drink even more. But before drinking he is found at the construction site or on the water training. While working on the canoes Sander is capable of using three tools at the same time. On the water it is even worse; just like hundred years ago there is an iron monster on the water. A man stopped only by an iceberg or by your little sister, so buy a gigantic freezer or make a sacrifice…

1.3. Reinforced by….

This paragraph is dedicated to the companies that support our project through financial sponsoring and through supplying the required materials. We want to thank these companies for reinforcing our project.

ENCI/ Heidelberg Cement Group
www.heidelbergcement.com

Besix Group
www.besix.com

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University of Twente
Faculty of Engineering Technology
School of Civil Engineering
www.cit.utwente.nl

Liaver
http://liaver.com/

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www.roodenberg.nl

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BMG Advies en Applicatie BV
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Scholz
http://www.scholz-benelux.nl

Buildsoft
http://www.buildsoft.eu

Study Association ConcepT
www.concept.utwente.nl

Drienerlose Kano Vereniging Euros
www.euroskano.nl

Part 2

CT2012 - A Winning Design

The second pillar for success in concrete canoeing is developing a winning shape and an optimal construction. The formulation of some design principles serves as starting point in the design process. When this part is covered one starts to develop the shape and an optimal construction. The shape of the canoe highly determines the hydrodynamic properties of the canoe which are of major importance in winning races. Finally, the construction of the canoe is the major factor in determining the canoes mechanical properties relative to its weight, with concrete being the binding element where the whole canoe relies on.

2.1. Principles of CT2012

In the previous challenges the BetonBrouwers where quite successful. A part of this success was based on the balanced design of the canoe, which provided the basis of the success. In this chapter the principles of the perfect shape are described, separating the principles for shaping the canoe from the ones related to the construction. The function of the craft is related to our general objective: creating a fast, innovative and robust concrete canoe design.

2.1.1. Shape principles

Shape principles are bounded by race regulations. Within this framework many degrees of freedom remain to optimize the canoes final shape. Therefore functional principles are formulated.

Performance criteria:

- **Crew –** The canoe must be propelled by two people with single-blade-paddles.
- **Length –** The length of the canoe must be at least 4m. The maximum length of the canoe is 6m.
- **Height –** The maximum height of the canoe is 1.0m
- **Width –** The minimum width of the canoe is 0.7m. It is not allowed to construct a canoe wider than 1.0m.
- **Failure –** The canoe must be provided with air chambers which prevent the canoe from sinking after breaking or capsizing. It is not allowed that the air chambers contribute to the stiffness of the canoe. The air chambers must be removable.

Functional Principles:

The functional principles, which ultimately lead to a competitive canoe shape, are derived with help of the well documented experiences of John Winters (Winters, 2005).

- **Displacement $D_{h;max}$;** Enough volume should be created to guarantee a floating hull under all conditions. In meeting this criterion a maximum displacement is assumed of 0.220 metric tonnes (2x80 kg for paddlers plus 60 kg for the canoe) over which a freeboard of 20 cm is sufficient to prevent wave overtopping.
- **Paddle positions;** In our philosophy, backed by some of Holland's top paddlers, the two headed crew should be placed in the bow and stern as far as possible, providing optimal canoe handling. This aspect is translated into a restriction in bow and stern angles. The hull beam should not be less than 0.3 m further than 1 m with respect to the canoes bow and stern.
- **Maximum Speed u_{max};** A function of the maximum speed [knots] of the canoe in relation to the length [feet] is provided by equation 1. Longer boats do increase displacement, drag and therefore decrease acceleration and manoeuvrability. Previous experience of our team and USA competitors favours long hulls over short ones since the loss in acceleration and manoeuvrability is well compensated by higher u_{max} and therefore the hull length l_h

  $$u_{max} = 1.34 \times \sqrt{l_h} \qquad (1)$$

- **Manoeuvrability and track ability;** A function of vertical curvature in the keel of the boat. The more the bow and stern are elevated relative to the boats turning point, the higher the manoeuvrability and the lower track ability. Based on earlier designs by USA competitors (Madison Concrete Canoe Team, 2008) show that a keel and bow elevation of 5 and 7.5 cm respectively give a good compromise of both aspects. This aspect is not changed for the 2012 design, since the model provided the best results for this keel and bow elevation.
- **Resistance;** Within the hull restrictions and the optimization aspects mentioned above, the hull is designed according to the KAPER formula formulated by John Winters. Two types of resistance can be distinguished. Frictional resistance (Rf) and Residual resistance (Rr). The combined effects of wetted surface, surface condition, surface length and speed comprise the resistance due to friction. Residual resistance is caused by wave resistance. With the formula the velocity-resistance graph can be drawn. The hull resistance of the 2012 canoe is the same as the 2011 and 2010 canoe, because the price of decreasing the stability in order to drastically decrease the resistance was too high. However the canoe has less resistance, because it is much lighter than the old one. So some changes are made to the canoe. These are described below.

Improvements
The new design has two main improvements in regard to the 2010 design, being:

- **Less weight**

  The upper shape of the canoe, is less curved than the CT2010 canoe. This is shown in figure 2.1 below. The orange canoe (CT2012, on the top) is less curved then the green canoe (CT2010).

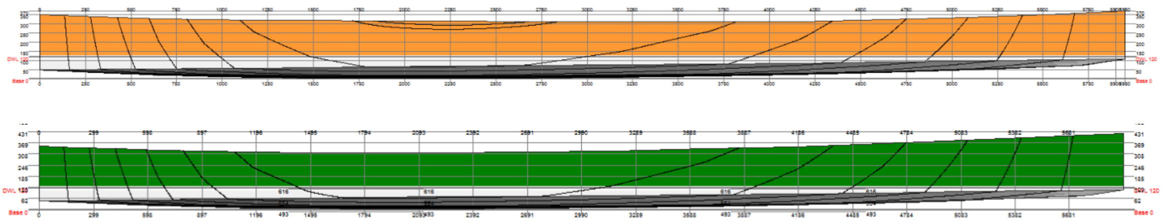


Figure 2.1: Canoe shapes of 2012 (upper) and 2010 (lower)

  With the less curved upper line of the canoe and a lower bow, the total surface of the canoe is decreased from 5,849 m^2 to 5,632 m^2. With a practical concrete density of 1119,5 kg/m^3 and a wall thickness of 5 mm, the reduction in weight is 1,214 kilogram. The main reduction in weight comes from the new concrete mixture, which drastically reduces the weight of the canoe. This will be described in part 3 of this report.

- **Stiffer canoe**

  The main advantage with the straighter upper line of the canoe, lies in the fact that the canoe will be stiffer. The canoe has a reinforcement steel cable in the top line of the canoe. If the line of the cable is curved, it will have the tendency to bend the canoe. When the trajectory of the reinforcement cable is much straighter, this tendency will be decreased and the canoe will benefit more from the reinforcement.

2.1.2. Construction principles

Just like the shape principles, the construction principles are bounded by the regulations. Besides the criteria derived from the regulations a set of functional principles can be formulated.

Performance criteria:

- **Concrete mixture** – The canoe must be constructed from (reinforced) concrete. The binding element must be cement (CEM I – CEM V) and the use of aggregates is obligated, although there are no restriction on the amount or particle size. Fillers and admixtures are allowed on the condition that they don't take over the binding function of the cement.
- **Reinforcement** – The strength and stiffness of the canoe must be derived from the collaboration between the concrete and the reinforcement. The percentage reinforcement is not restricted. The concrete must be the determining factor concerning the stiffness of the canoe, the reinforcement itself is not allowed to have a considerable stiffness.

Functional Principles:

- **Waterproof –** The skin of the canoe must have a low porosity to such a degree that it can be considered waterproof under nautical conditions.
- **Mechanics –** Based on the expected forces on the construction, estimation can be made of its dimension (thickness) and the necessary reinforcement. Hereby it is also necessary to take into account the dynamic forces, following from the nautical function of the construction.

2.2. The art of shaping a concrete canoe

CT2012 is designed by using the software package Delftship 4.30.108. Thereby we consulted people of the Maritime Research Institute Netherlands (Marin) to discuss the possible improvements.

The shape principles as defined in section 2.1.1 give clear restrictions in the optimization of the hull. Stability was guaranteed by evaluating the programs output parameter Keel Mark *KM* which is a measure for stability. This value is kept the same as the CT2010 design, since this proved to be a very stable canoe. The optimization function was the hulls resistance measured by the KAPER method, described by John Winters. See figure 2.2 for the modelled canoe in Delftship.

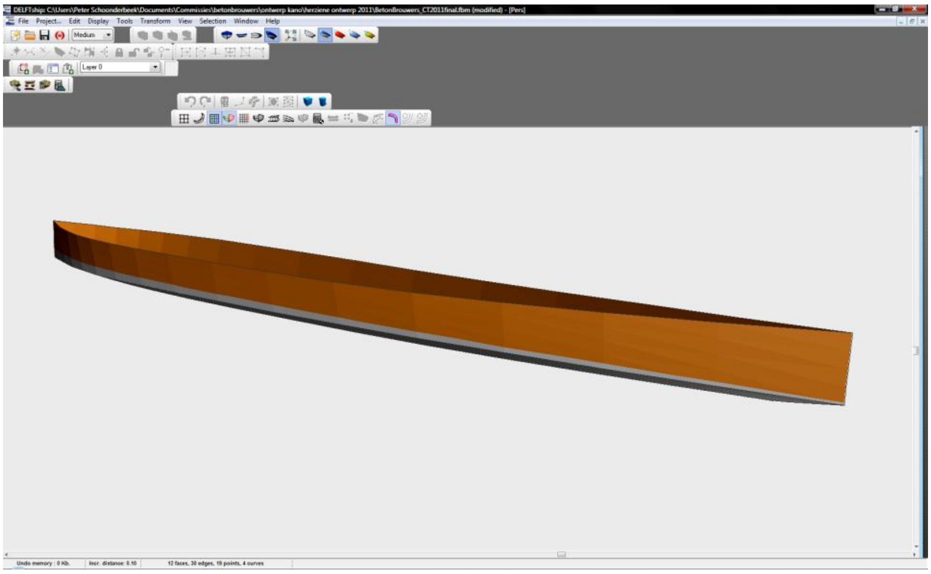


Figure 2.2: CT2012 as modeled in the software package Delftship

For the final design the resistance graph is given in figure 2.3. The CT2012 design has the same hull shape as the CT2010 design, however the resistance is lower. This is because the canoe is lighter and therefore has less wetted surface resulting in a lower resistance. The total resistance of the canoe at 6 knots is 0.061 kN. The CT2010 design has a resistance of 0.0641.

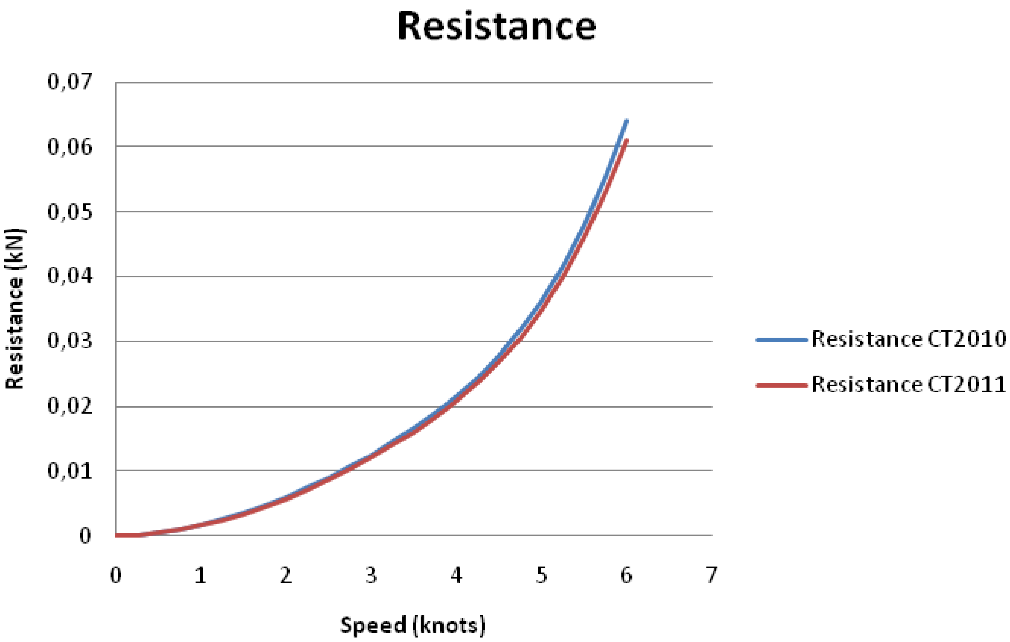


Figure 2.3: CT2012 Hull-resistance

Though the difference in resistance might seem small, the increase in performance is 5% over the entire trajectory, which should lead to a clear victory for our fit paddlers. The secret behind this result is a keen *L/B* ratio, whereby the maximum beam is reduced to 0.71 m, just above the minimum required for the German competition. Moreover, the maximum beam is placed further to the stern, leading to a very low angle at the bow part of the hull. The length is optimized to 5.85 to ensure a high top speed at the straight. The high prismatic coefficient favours the paddlers comfort during the race, but also reduces draft, therefore the hull area which is submerged and ultimately leads to a lower resistance. The lower draft also favours manoeuvrability. The loss in track ability is compromised by a high L/B ratio.

2.3. The Secret of Strength, Stiffness and Stability

Since in our academic philosophy a well engineered design should always be backed by a sound mechanic hull assessment, we started the design of CT2007 with the necessary mechanical models to determine the canoes maximum stresses under most unfavourable conditions (BetonBrouwers, 2007). Though these models provide a good first indication of the strength required, they are also limited in the practice of concrete canoeing, since hull stresses under race conditions are hard to model.

In the academic triptych of Strength, Stiffness and Stability we based our first design on sound principles as described in the construction report of 2007. Since the CT2012 concerns a different design, a new mechanical analysis is carried out to gain insight in the forces on the hull. Over the last years we experimented with the resulting design which brings us to an evaluation which we translated into Achilles Heels and solutions. For the CT2012 model, a new mechanical analysis is carried out.

2.3.1. Mechanical Analysis

In order to carry out a mechanical analysis, insight in the forces acting on the hull is required. The load on the hull is determined by four components:

1. The weight of the paddlers: $F_{paddler}$ [N]
2. The weight of the canoe: F_c [N/m]
3. The upward water pressure: q_w [N/m]
4. The water pressure on the bow: F_w (N)

For the weight of the paddlers, it is assumed that they weigh 800N each. Our atheletes are assumed to be in top condition, don't use doping and drink just one beer a day. The weight of the canoe can be determined from the hull surface, the thickness of the wall and the density of the concrete. This results in a F_c of 600N, leading to an q_c of 100,8 N/m. The water pressure is determined by the weight of the paddlers together with the weight of the canoe (2200 N), divided by the length of the canoe (5,95 m): q_w = 369,8 N/m. Concerning F_c and q_w it is assumed that they are opposite of each other, giving a resulting force: q_{res} = 268,9 N/m. Furthermore a water pressure is acting on the bow of the canoe, this is assumed to be 100 N (equal to a water pressure of 10 kilogram on the bow because of the water displacement and waves acting on the bow)

2.3.1.1. Input

To calculate the real forces acting on our canoes, the software package 'Buildsoft' is used, a software package that can calculate stresses and deformations in our canoe. In figure 2.4 the forces acting on the canoe are shown, the figure shows the how the forces acting on the canoe are modelled in Buildsoft.

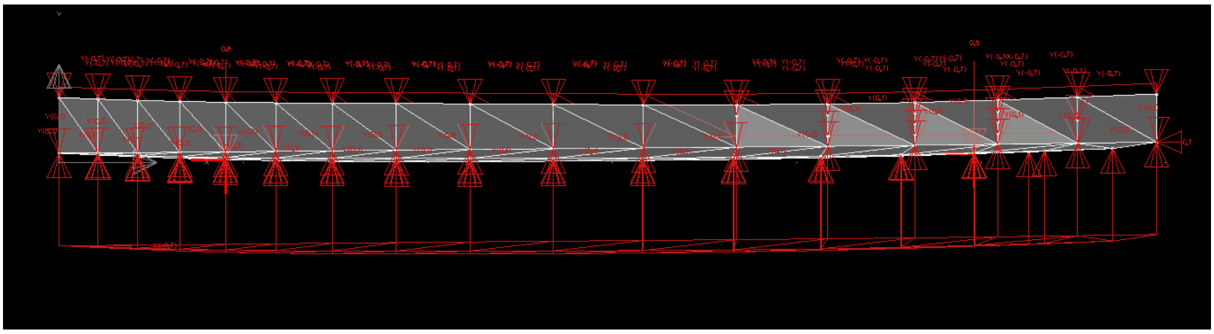


Figure 2.4: Force analysis on CT2012

First the hull design was modelled in Buildsoft, the result can be seen in figure 2.5. The input for the mechanical analysis is:

- Concrete: C25/30
- Thickness of the walls: 5 mm
- Density of the concrete: 1020,5 kg/m^3
- Weight of the paddlers: 80 kg
- Position of the paddlers: 0.75m from the bow and 0.5m from the stern.

With this input the mechanical analysis is carried out. The canoe is modelled as a raster of triangles, with plates between these triangles that form a watertight canoe. In order to calculate the forces acting on the canoe (shown in figure 2.5), the program makes a fine raster of triangles (see figure 2.6). This analysis doesn't take into account the loads and stresses on the canoe hull as result of transport, paddling and possible impacts.

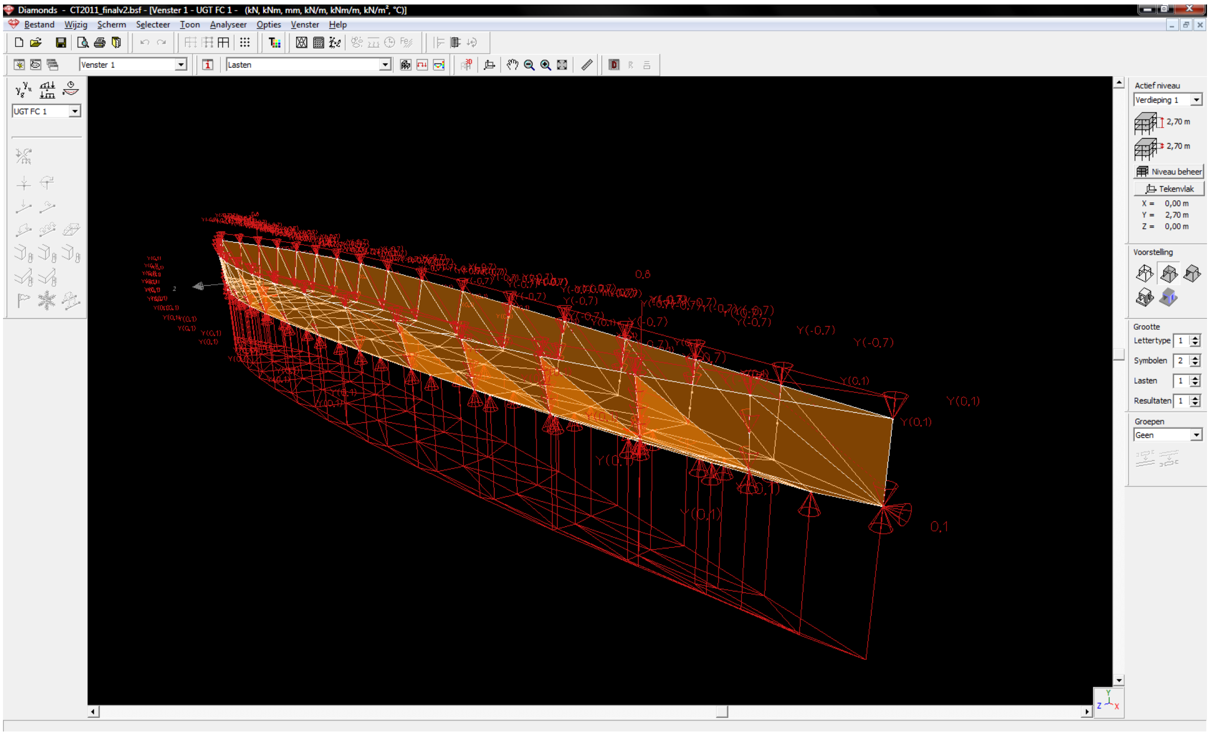


Figure 2.5: Forces acting on the canoe

Because the rotation or movement of the canoe must be prevented, two points are added to prevent the canoe from rotating or moving. These two points are made at the point where the two forces of the paddlers are acting on the canoe. Because of this measure, the canoe does not deform precisely as in reality, but it is a very good approximation of the real deformation of the canoe. The result of the analysis are discussed below.

2.3.1.2. Results of the analysis

Tensions in the canoe

Since concrete is not able to cope with tension it is important to obtain a good insight in the locations where tensile forces act on the canoe. The concrete can have 2,6 N/mm^2 tensile force and 15 N/mm^2 compressive force (0,6 * 25 N / mm^2, in order to be safe). Figure 2.6 shows the tensions in the concrete. The bright red colours indicate that the maximum tensions in the concrete are exceeded, reinforcement on the spots is absolutely necessary in order to keep the canoe intact.

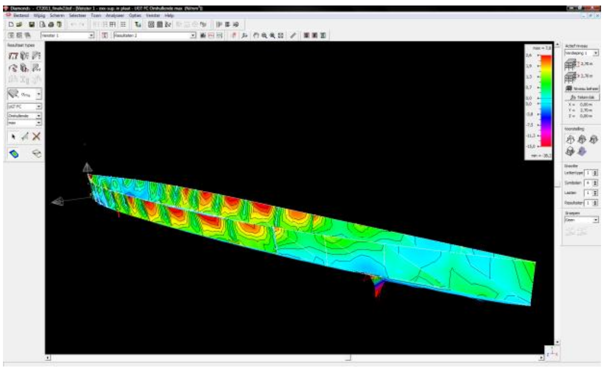


Figure 2.6: Modeling tension on the canoe

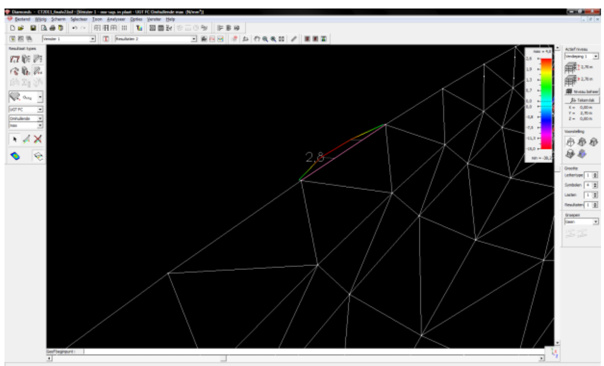


Figure 2.7: Tensile strength in side wall of the canoe

Figure 2.7 shows that the tensile strength of the concrete is also not big enough in the side walls of the canoe. The large forces in the longitudinal section occur at 2/3 of the length (see figure 2.6). So reinforcement is placed by putting two steel cords in top of the walls. These should compensate a normal force (σ_n) of about 2,8 N/mm^2 (see figure 2.7). The cords are stressed with 10 kN when the concrete is sufficiently hardened with anchors at the bow and stern, and are called after-stressed cords. These cords are from now on referred to as 'type 2' cords.

Deformation of the canoe

Beside tension in the canoe, the forces acting on the canoe result in a tendency to deform. The figures below, figures 2.8 – 2.10, show how the canoe has the tendency to deform under the pressure of the forces acting on it. The deformation is exaggerated in order to show how the canoe has the tendency to deform. This deformation must be countered with reinforcement.

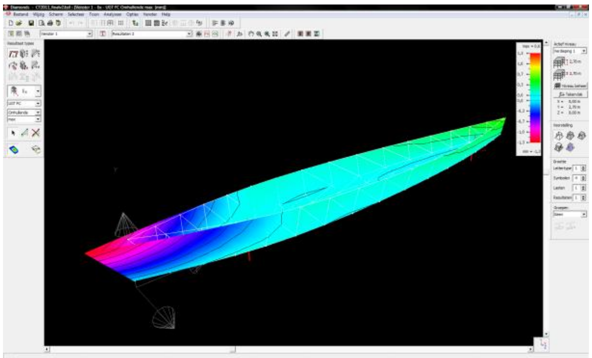


Figure 2.8: Tendency to deform in the length direction (x)

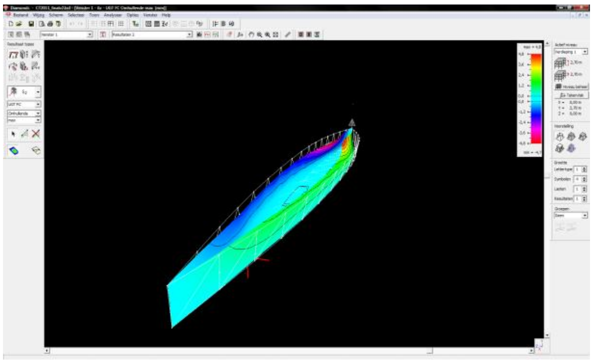


Figure 2.9: Tendency to deform in the height direction (y)

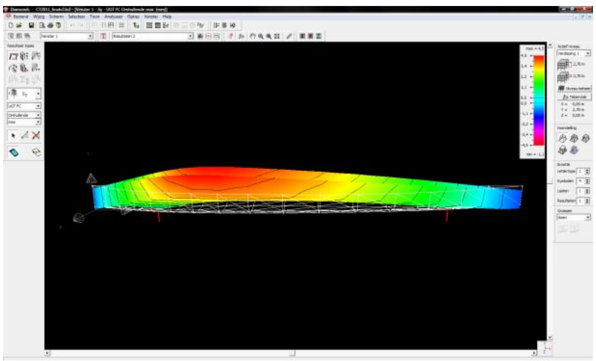


Figure 2.10: Tendency to deform in the width direction (z)

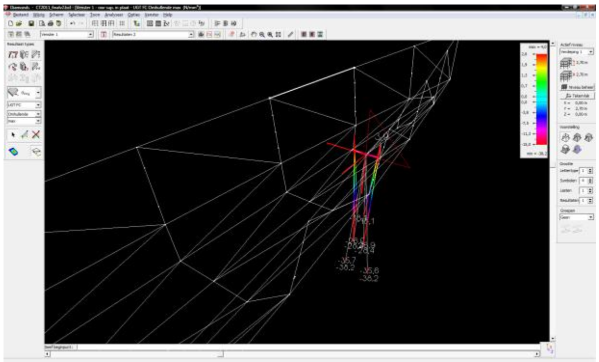


Figure 2.11: Insight in forces caused by the paddler

From the mechanical analysis that concrete with a compressive strength of 25N/mm^2 or higher is sufficient, except for the positions where the paddlers are. However, since the force of the weight of the paddlers is modelled as a point force, this force is extreme (38,2 N/mm^2). See figure 2.11 for a closer look. In reality this extreme force of 38,2 N/ mm^2 is distributed over a bigger surface. Even if it's an area force over 6 cm, the force will be (38,2 + 3,9 = 42,1 N/mm^2 / 6 cm = 7 N/mm^2 per centimetre. So the compressive strength of the concrete is great enough. However, because the concrete also will have tensile forces at the positions of the two paddlers that exceed the maximum of the concrete, cracks are likely to arise. So on the position of the paddlers high forces are acting on the canoe, therefore pre-stressed cords are certainly required. In the length direction of the canoe, three pre-stressed steel cords are placed, pre-stressed with 10 kN. These cords will from now on be referred to as Type 1 Cords. Also, in the width direction, on the two positions of the paddlers a steel cord (type 1) is placed and pre-stressed with 500 kN.

2.3.2. Achilles heels

Next to the mechanical analysis, we also have experiences from previous years. This experience is shown below, where the Achilles heels of the canoe are mentioned and countermeasures are made.

Achilles Heel 1 – Bottom of Mid Cross section
When lifting a concrete canoe at the bow and stern the maximal momentum of the canoe is found in the mid section. When the length view is considered, a critical vertical line can be drawn over which this momentum is transferred into pressure in the top and tensile stress in the bottom. This force is compensated by the pre stress of 10 kN in the bottom of the canoe by the three steel cords (type 1 cables).

Achilles Heel 2 – Top of Mid Cross section
When the same cross section is considered problems emerge in marine conditions. When the canoe is propelled by two paddlers located in the far bow and stern, most of the downward force is applied in these locations. The upward reaction force, however, is equally distributed over the canoe hull. Over the last two years many teams have seen cracks caused by this problem. This problem solved with the two types two steel cords in the top of the walls of the canoe.

Achilles Heel 3 – Cracking under its weight and water pressure
At CT2007 we observed a crack in longitudinal direction of the canoe. It is believed that this crack occurs when the canoe is rested on its bottom. Since the bottom is slightly curved in both directions, the weight of the sides is transferred to the middle, which couldn't cope with these high stresses, resulting in a crack at the inner side of the canoe. The opposite occurs when water presses on the sides of the hull. In this case the tensile stress occurs in the outer side of the hull, but over the same profile. To overcome this problem an extra cords is used in the middle of the canoe to increase stiffness. To even further decrease this problem, the cord (type 1) is pre stressed over the width of the canoe. The cords are pre stressed under 500 N of pre stress, just as the two other cords at the place of the paddlers.

Achilles Heel 4 – Extreme stress under race conditions
Though static evaluations can reveal some weak points in concrete canoes, extreme stresses occur under racing conditions, where the stress distributions are very dynamic. Modelling hull stresses over time is not possible, wherefore a simple philosophy is applied: '*if it bends, it doesn't break!*'. Over the entire hull two layers of stucco-mesh are applied which distribute the stresses from the hull to the cords and the mechanical structure, and to make sure that the canoe can have more impacts without cracking, caused by extreme racing conditions. These meshes are a combination of plastics and glass fibres with a mesh diameter of 5x5mm.

Based on the mechanical analysis and the Achilles Heels, the reinforcement of the canoe consists of:

- three pre-stressed steel cords (type 1) in bottom of the canoe over the whole bottom length (x) of the canoe (see 1, *figure 2.12: Blueprint of CT2012*)
- four pre-stressed steel cords (type 1) in the bottom of the canoe over the whole bottom width (z) of the canoe (see 2, *figure 2.12: Blueprint of CT2012).*
- two post-stressed steel cords (type 2) in the top of the side walls of the canoe over the whole top length (x) of the canoe (see 3, *figure 2.12: Blueprint of CT2012*)
- full body mesh

So with this reinforcement, the canoe is strong enough to cope the static forces as modelled in Buildsoft. Also, it is able to withstand the dynamic forces and the extreme stress conditions it is subjected to (some of them causing the Achilles heels).

2.4. The Blueprint of CT2012

The blueprint of CT2012 is given in *figure 2.12: Blueprint of CT2012*. It gives a top view, side view as well as two cross sectional views. Incorporated are the steel reinforcement cords. The stucco-mesh is not shown.

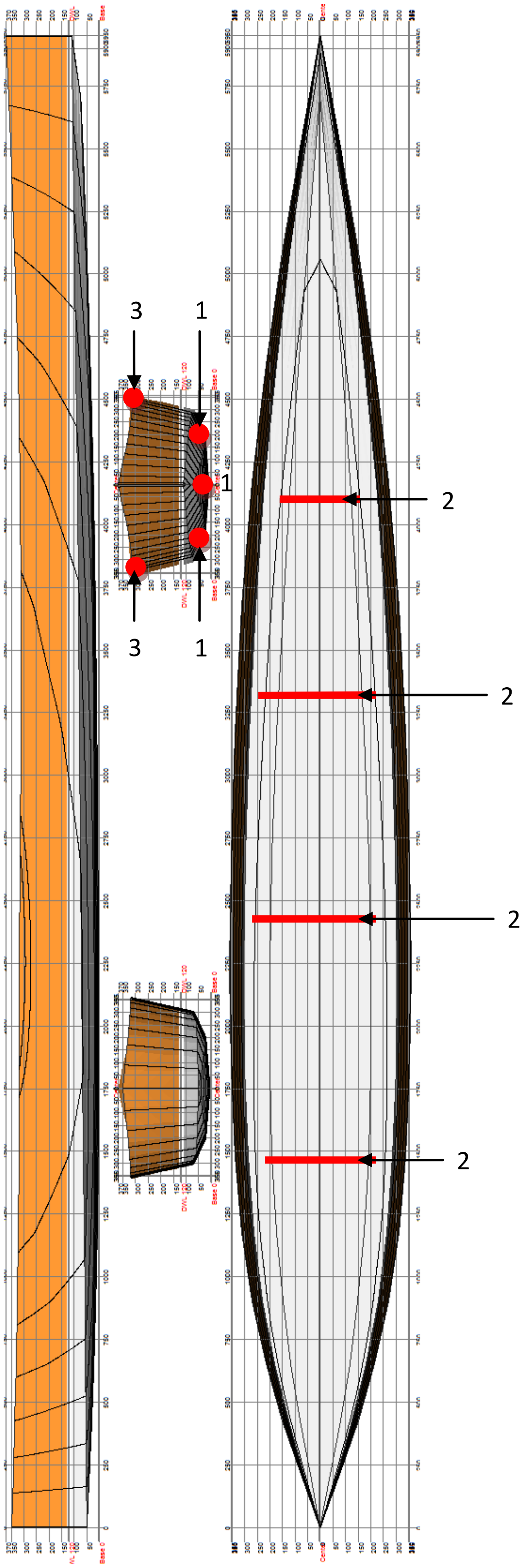


Figure 2.12: Blueprint of CT2012

Part 3

CM2012 - The binding element

The third pillar for success in concrete canoeing is developing an optimal concrete mixture. During their study Civil Engineering, students acquire a broad theoretical background concerning the fascinating material concrete. This background in combination with the experiences from preceding years serve as valuable input for the composition of the mixtures. Optimizing the compositions based on the particle size distribution is the last step before entering the concrete lab. During long days in the concrete laboratory the mixtures are analysed on their workability, colour and strength. The result: the optimal mixtures to serve as binding element of the canoe.

3.1. The theory behind concrete

Before one starts composing a concrete mixture, it is important to understand the principles behind the material. Therefore it is important to be familiar with the (basic) theory behind the material and/or have some experience with it. In this section the basic theory behind the material concrete is highlighted. This basic theory is derived from the compendium 'Concrete Technology 1' from the Department of Structural Engineering of the Norwegian University of Science and Technology (NTNU).

3.1.1. Concrete

In general concrete is a mixture of cement, mineral additives (such as pozzolans), aggregates (gravel, sand), water and admixtures. The coarse aggregates make up approximately 70% of volume, cement paste makes up around 30% of the volume. For the application on our concrete canoes this ratio is slightly shifted.

Both material choice and proportions of the materials, i.e. the proportioning, determine the properties of the concrete for both fresh and hardened condition. Both very important when constructing a concrete canoe. It is possible to control this to a large extent, but improvement of one property will often lead to worsening of some other property. One will therefore constantly be facing an optimization of prioritized properties.

Cement:
Cement is the binding element within concrete. The most common used cements are Portland clinker and derivates of Portland clinker, containing slag, pozzolana or fly ash. According to their composition, the cement types are divided into five main types, being: CEM I, CEM II, CEM III, CEM IV and CEM V. Cement mixed with water is often called cement paste. The properties of the cement paste are mainly determined by the mass ratio between water and cement, the w/c-ratio.

Mineral Additives:
The most common used additions are Fly Ash (FA), Silica Fume (SF) and blast-furnace slag, also termed pozzolans. All three of these additions are industrial by-products. When used in concrete they reduce the demand for Portland cement clinker. Hence their use is advantageous both from economic and environmental points of view – particularly w.r.t. reducing the large amounts of CO_2 emission associated with Portland cement production.

Pozzolana are active mineral additions. This implies chemical reactivity either alone or in combination with Portland cement clinker and/or its hydration products. Pozzolans are included in the mass ratio m = w/(c+k*p), where k is an efficiency factor for the actual property and the actual material. Non active additions are also used extensively, and are commonly referred to as fillers, i.e. normally finer than 125µm and close to chemically inert. Note that fillers may be chemically inert, but may accelerate cement hydration by providing surfaces for precipitation of hydration products.

Aggregates:
Aggregates have an important influence on the concrete properties, both in the fresh- and hardened state. In our project only fine aggregates (0-1mm) are used as a result of the thickness of the canoe. Important factors to keep in mind when selecting an aggregate are the material grading, the particle shape and water absorption. In our project it is not very important to have a high durability, the canoes are used for only one year. Despite that we want to develop a high-quality concrete, and thus take into account the durability. A very important issue for a concrete that requires a high durability are Alkali-Aggregate-Reactions (AAR). AAR are reactions between certain aggregate types and the alkaline pore water in the cement paste. A certain amount of moisture is required within the concrete. During the reaction a gel is formed in the concrete. This may suck water and swell, which can lead to a volume increase and cause a characteristic crack pattern on the concrete surface after several years. Three condition must be fulfilled before AAR will occur: Alkalis, Water and Reactive aggregates.

Admixtures:
Admixtures are chemical agents added in small dosages to improve certain properties of the concrete. The European Standard (EN 934-2:2001) defines an admixture for concrete as: *"Material added during the mixing process of concrete in a quantity not more than 5% by mass of the cement content of the concrete, to modify the properties of the mix in the fresh and/or hardened state."*.

3.1.2. Lightweight concrete

To construct the concrete canoes, lightweight concrete is used. Generally speaking, lightweight concrete includes all types of concrete with density less than 2000 kg/m^3. At mixing, lightweight aggregate (LWA) will absorb water from the cement paste and a larger loss of workability in the form of slump loss than in normal density concrete results. As a consequence of the absorption into the LWA, the real or effective mass ratio (w/c or w/b ratio) is reduced, this must be taken into consideration.

3.1.3. Workability

Because of the casting technique of the concrete canoes, the workability of the concrete is a very important aspect concerning the composition. The workability of concrete depends on the properties of the constituent materials, their relative proportions and physical and chemical interactions between them. The properties of fresh concrete can be described by the concept workability. The workability concept may be divided into three basic elements: stability, mobility and compactability.

Stability:

Stability may be defined as the ability of concrete to retain its homogeneity through the fresh phase, both at rest and subject to loads to transport, form filling and compaction. Lack of stability may lead to separation. There are three different forms of separation. Separation of water occurs in ordinary concrete qualities, paste separation occurs mostly in high strength concrete, whereas separation of mortar and coarse aggregate occurs in both ordinary and high strength qualities.

- Separation of water, or ‘bleeding’ is characterized by a part of the water in the concrete flowing upwards to the concrete surface, collecting in pockets under coarse aggregate and forming a film of water at the surface.
- Paste separation can arise as one tries to obtain flowing concrete consistency and the amount of cement paste is too large compared to the amount of sand, or as the sand partly lacks the finer fractions.
- Mortar- of coarse aggregate separation or ‘segregation’ occurs as the coarse aggregate sinks in the concrete, and mostly results from inadequate aggregate composition by the partial or complete lack of certain aggregate sizes.

Mobility:

Mobility may be defined as the ability of the fresh concrete to move due to forces acting on it. The resistance against motion depends on:

- Friction between particles
- Internal cohesion
- Resistance to internal flow of the liquid phase

Compactability:

The ability to be compacted is the ability of fresh concrete to fill out the formwork and let off encapsulated air pockets during reworking. Effective compaction is one of the most important factors determining to which extent the concrete strength potential can be exploited.

3.1.4. Proportioning

Proportioning concrete means selecting materials and putting them together so that:

- The hardened concrete obtains required properties with good margin
- The fresh concrete obtains sufficient workability to be placed and compacted with the actual method
- Low risk of errors

The following basic rules apply when proportioning concrete from scratch:

- The matrix composition controls the properties of the hardened concrete. The cement paste has in most cases lower durability and strength than the aggregate (“the weakest link”). Therefore the required compressive strength and durability of the concrete controls the matrix composition.
- The aggregate composition controls the properties of the fresh concrete. The properties of the aggregate (shape, particles size distribution and void content or packing) determine how large the matrix volume must be to give desired or required workability.

3.1.5. Strength

The definition of strength is as following: the strength is the average value of maximum load converted to nominal stress for a series of standardized specimens loaded until failure in a given load test-set up.

The tensile strength of concrete is low compared to its compressive strength, 10-12% for ordinary structural concrete, 4-6% for high-strength concrete. In the design of concrete structures one usually assumes that all tensile forces must be taken care of by the reinforcement. Still, for some cases, it is obvious that the tensile strength is significant. The tensile strength of concrete will to a high degree govern if and how cracking possibly will occur in tensile zones, and possibly affecting the durability of the concrete.

The concrete should have enough strength to cope with the forces as discussed in the mechanical analysis (Part 2). Factors that influence the strength potential of the concrete are:

- Cement type: The clinker composition of the cement influences the strength potential because the clinker leads to different hydration products and structure in the cement paste.
- The fineness of the cement: Normally the strength potential will be larger at higher grinding fineness. This is due to the fact that larger reaction surfaces lead to larger degree of hydration, and thus lower porosity.
- Properties of the aggregate: in our project the mechanical properties of the aggregate can become a limiting factor.
- Degree of compaction: Lack of compaction causing large voids, cavities and discontinuities in the concrete, and reduced strength.
- Curing conditions: Early drying gives reduced degree of hydration and risk of cracking due to shrinkage. Both factors will lead to reduced strength.
- Temperature level: High curing temperatures is unfavourable for the porous structure formation in the cement paste and will reduce the concrete strength. Large temperature differences in the cross section lead to strain differences and possible cracking.
- Air entrainment: a good rule of thumb states that the compressive strength is reduced by 5% for each 1% air.

In general concrete becomes more brittle as the strength level increases. Concerning the concrete canoes a more flexible concrete is desired. Therefore it is important to develop a concrete that is strong enough to cope with the forces acting on it, but doesn't becomes too strong.

3.1.6. Porosity & Permeability

The internal consequences of the hydration are large changes in solid volume and thereby in the porosity. Porosity means here the internal volume that can be filled with water.

The reaction of water and cement during hydration is associated with a volume change, i.e. the volume of the reaction products is smaller than the volumes of the reactants cement and water. When looking at the permeability coefficient (K') for stationary water transport in well hardened cement paste at different w/c-ratios, and as a function of hardening time for a fixed w/c-ratio, two effects become clear:

1. Improved hydration reduces both the porosity and the continuity in the pore system, which reduces the K' with a large magnitude.
2. Over a w/c-ratio of approximately 0.50 increase K' markedly with increasing w/c-ratio as the volume of capillary pores and their continuity are increasing sharply.

The general international requirement is that "watertight" concrete shall have a w/c-ratio below 0.50.

For a given w/c-ratio the permeability is increasing with D_{max} of the aggregates. The reason lies in the transition zone between aggregates and paste. Another factor that has a negative influence on the permeability is drying from early age. This is unfortunate since the surface might experience low degree of hydration and cracks might form with reduced permeability as a result. Since our canoes don't have any coating (like paint) and the walls are very thin (max 5mm), it is important to keep the permeability in mind.

3.1.7. Curing

When cement is hydrated, considerable amounts of heat develops. In most concrete structures this leads to temperature increase the first days after casting. High temperature results in fast hydration and thus fast strength development. The heat of curing can also lead to damage (cracking) or reduced material quality in massive structures unless the heat evolved and resulting temperature increase is not taken care of in a controlled manner. Since our canoes have very thin walls, the temperature will not reach a level at which it leads to damage.

In order to achieve a full hydration and therefore increase the impermeability of the canoe it is important that the concrete is cured in a moist environment.

3.1.8. Cracking

As mentioned before, concrete is a material sensitive for cracking. Generally cracks develop due to:

1) Volume changes produced by the concrete itself
    a. Plastic shrinkage: caused by water evaporating from the surface of the concrete during the fresh phase. Measures against this type of shrinkage are moderate watering and/or covering the surface (for example with a foil).
    b. Plastic settlement: the downward (vertical) movement of the solid particles in fresh concrete. Measures are reducing the bleeding tendency and early covering to avoid evaporation.
    c. Autogenous shrinkage: the concrete's self-produced shrinkage and it is determined by the choice of constituents and the concrete mix design. The reaction between water and cement is associated with a loss in volume because the reaction product fills a lesser volume than the reactants. The phenomenon is called chemical shrinkage and is a fundamental property of cement hydration.
    d. Thermal effects: the concrete structure moves thermally, it expands during the heating phase and contracts during the subsequent cooling phase.
    e. Drying shrinkage: hardened concrete surfaces exposed to dry air will gradually dry out and develop drying shrinkage. Drying shrinkage consists of a reversible and an irreversible component.
2) Degradation
3) Loads (own weight, working load, etc.)

The volume changes and cracking tendency may be strongly influenced by the concrete constituents and their volume proportions. Therefore it is important to keep these cracking mechanisms in mind when composing a concrete mixture. The reinforcement is considered to prevent cracking as a result from the loads.

3.2. <u>Composition of the mixtures</u>

In this section the concrete mixtures 2012 (CM2012) are composed. For the composition of a mixture is it important to know what kind of concrete you are looking for. Based on the objective the ingredients of the mixture can be determined. Taking into account the properties as mentioned in paragraph 3.1. The second step is to proportion the materials, this is done based on the particle size distribution. In addition to our own (basic) knowledge concerning concrete and the experiences from preceding years, a workshop was organised at the ENCI to develop the new mixture.

3.2.1. The Objective

The objective concerning the concrete mixture is to develop a impermeable lightweight and sustainable concrete that can cope with the forces acting on it. This year the aim is to make black canoes with a red "Twents Ros" (also of concrete) casted in it. Both of the same mixture only with different pigments. Another aim this year is to really calculate the final density of the concrete, previous years the calculated density was different from the real density, therefore a sharp look will be taken at the used aggregates in the concrete, in order to determine whether they are as light as expected.

<u>Colour:</u>
This year the aim of the BetonBrouwers is to make black canoes with in red concrete a small horse inside it. Since black is a really hard colour to make in concrete, within this we got ourselves a challenge.

<u>Permeability:</u>
The easiest way to make the canoes watertight is to use a coating (paint, varnish, etc.). But since we want to show the material itself with a casted red horse in it, painting is not an option. Thereby we want to show the full potential of concrete. With a little more effort during the development of the concrete, it is possible to develop a concrete mixture that is watertight itself. Therefore we don't want to use any other type of coating

(like varnish). Since our walls are just 5mm thick, it is really important to keep the influence of the ingredients on the permeability in mind.

Density:

The lower the density of the concrete, the lighter the canoe will become. The lighter the canoe, the faster the top speed is reached, the easier the canoes can be carried and the smaller the change of cracking as result of its own weight. Enough reason to reduce the density of the concrete were possible. The density of the concrete is largely determined by the aggregate. A use of lightweight aggregates seems to be necessary. Since the density of the 2011 concrete was 1255 kg/m^3 the objective is to decrease this, if possible below 1000 kg/m^3.

Sustainability:

Over the last years the environment is getting a more and more important issue. This environmental awareness can be noticed in the concrete industry as well. Although our canoes require small amounts of concrete and are used for just one year, there is no direct need to develop a sustainable concrete. Despite that we would like to contribute to a healthier world. Thereby concrete has an unjust negative image concerning its environmental impact. Therefore we want to develop a sustainable concrete.

Develop a sustainable concrete is a combination of three phases. During the developing phase one can chose renewable/recycled materials and/or chose local materials. For the second phase it is important that the concrete has a high quality and is durable. The longer the concrete stays in good condition (no cracks or other degradation) the longer the lifespan and the smaller the environmental impact. The third phase is the recycling phase. In case the concrete can be reused (road filling or as aggregate in new concrete) in case a construction is broken down, it is more sustainable than in case it is considered as waste.

3.2.2. Ingredients

The first step in composing the mixture is to select the materials. Since every material has its specific characteristics and contribution to the mixture, this chapter highlights the materials used in our canoes.

Cement:

The Heidelberg Cement Group provided us of cement, being:

- CEM I 52.5R LA – White

This is a white cement and therefore will attribute to the best colours. Thereby the addition 'LA' is indicating that it has a Low Alkali content. This means that the cement has a limited alkali content. This low alkali content has a positive influence on the durability of the concrete since it reduces the occurrence of AAR.

Aggregates:

Aggregates are the bearing material in concrete. It has an important influence on the concrete properties, both in the fresh- and hardened state. Aggregates can be distinguished in grain size. Sieve curves determine how much aggregate from each grain size is needed. The aim is a perfect fit for small and bigger grain sizes, such that there is no space left for air. Other important factors to keep in mind when selecting an aggregate are the particle shape and water absorption.

Our aim is to make the canoes as light as possible. Since we work with thin walls (< 5 mm) and we want to keep a good workability we need small grain sizes, no bigger than 1 mm. As lightweight aggregate the LIAS Benelux Company provided us expanded glass, called Liaver 0.1-0.3, Liaver 0.25-0.5 and Liaver 0.5-1.0. Also Liaver fines (glasmehl) were considered this year, this is a fine material, which is still lighter than cement. The density of the materials is checked by using a pycnometer, because the idea was there that differences in density could be caused by the aggregates, the densities of the Liaver fractions were tested. The results were interesting and showed us where the density differences came from and a shown in table 3.1. Some more specifications of the materials are shown in table 3.1 and the sieve curves can be found in Appendix C.

Type	Particle density	Particle strength	Water absorption
Liaver 0.1-0.3	970 kg/m^3	> 3.5 N/mm^2	1.5 mass%
Liaver 0.25-0.5	570 kg/m^3	> 2.9 N/mm^2	3.0 mass%
Liaver 0.5-1.0	480 kg/m^3	> 2.6 N/mm^2	4.0 mass%

Table 3.1: Specifications of the used Liaver [Source: Datenblatt Liaver, 2010]

Mineral additives:

Mineral additives are fine substances (<63µm) which can be added to the concrete to increase the amount of fine material. Mineral additives can be inert (non-reactive) or pozzolana, which means the substance becomes solid after the reaction with water and calcium hydroxide. We selected two materials as mineral additives, being Microsit and silica fume.

Microsit which is a sieved fly ash, is available in all wishful sieve sizes and therefore can be adjusted to the required sieve size. Therefore the following Microsit was selected: Microsit M20. This was selected because of the following reasons:

- The finesses exactly fits to our particle-size-distribution matrix and therefore has a positive influence on the permeability and workability of the concrete.
- It reduces the amount of water necessary in the concrete and therefore results in a higher strength
- A part of it lays in the same particle size of cement but the density is lower than cement
- It is sustainable because it is a rest product of the garbage burning plants

The sieve analysis of microsit is given in Appendix C, because of long delivery times also regular fly ash was tested.

Silica fume is selected because of the following reasons:

- The small grain size increases the strength
- The small grain size decreases the permeability
- It is a sustainable product
- It contributes to the final strength of concrete.

Admixtures:

Admixtures are parts of the concrete composition (<5 mass%), who achieve a significant modification in the properties of the cement paste and/or the concrete. In our concrete three types of admixtures are used; super plasticizer, retarding admixture and pigments.

Super plasticizer

The main role of (super) plasticizers is to disperse flocculated cement particles in water. (Super) plasticizers can be utilized in different ways:

- Constant strength and water content
- Constant workability and cement content
- Constant workability and strength
- Increased workability

For our purpose the super plasticizer is used to increase the workability of the concrete.

Retarding admixture

Chemical admixtures affecting the hydration of cement to produce a delay in the process of cement paste stiffening and/or rate of hydration are termed retarding admixtures. Since the casting of the canoe takes about 5 hours, it is important that the hardening of the first batches of concrete is delayed. In this way the first chemical bonds are not destroyed during the casting process.

Pigment

Our aim is to build canoes with two different colors. Therefore Scholz delivered us two different colors of pigment,; Scholz black (HS 25235) and Scholz Red (HS 130 P).

Result:
In the table below the ingredients for the concrete mixtures of 2012 are listed.

Material:	Supplier:	Function:	Details:
CEM I 52.5R LA – White	CBR	Binding element	-
Microsit M20	Baumineral	Improve properties	-
Silica Fume	RW Silicium GmbH	Improve properties	-
Liaver 0.1-0.3	Liaver	Lightweight aggregate	Water absorption: 1.5 mass%
Liaver 0.25-0.5	Liaver	Lightweight aggregate	Water absorption: 3.0 mass%
Liaver 0.5-1.0	Liaver	Lightweight aggregate	Water absorption: 4.0 mass%
Red pigment (HS 130 P)	Scholz	Colour	-
Black Pigment (HS 25235)	Scholz	Colour	-
Plasticizer	Basf	Improver workability	-
Retarder	Cugla	Delay hydratation	Add 0.3% of cement weight
Water	Vitens	Hydration	-

Table 3.1: Ingredients concrete mixtures 2012

3.2.3. Mixtures

The second step is to determine the optimal composition. Firstly together with Dr. I Stipanovic the ideas for this year were developed concerning the concrete mixture. With these ideas a workshop was organized at ENCI. During the workshop at the ENCI in Rotterdam we gained some new ideas and composed three mixtures based on the concrete mixture of 2010. In order to determine the optimum composition the mixdesign method of ENCI is used. The proportioning of concrete mixtures, also referred to as mix design, covers the combination of varying ingredients to produce concrete of appropriate workability, strength and durability. The composition of a good and workable concrete mix shows that the granulometric properties of the aggregates are of utmost importance as a strong relationship exists between the granulometric properties of the aggregates and the concrete properties in fresh and hardened stage. The concrete properties are strongly influenced by the particle packing of the aggregates and the therewith connected granulometric properties.

Based on the workshop at ENCI Rotterdam and the selected ingredients, several mixtures are composed. Since this is an iterative process, several series of mixtures are composed and tested. Below these mixtures are shortly explained, their exact composition can be found in appendix B.

Colour mixtures		*Adaption mixture 2011*
Mixture 1	Series 0	Replacing the pigment for black pigment in order to choose the best pigment
ENCI mixture		*Low cement amount, combine all different materials*
Mixture 1.1	Series 1	CEM, Fly ash, glasmehl microsilica
Mixture 1.2	Series 1	CEM glasmehl, microsilica
Mixture 1.3	Series 1	CEM, Fly ash, microsilica
Combined mixtures		*Choosing the right materials*
Mixture 1.4	Series 2	Based on 1.2, different composition
Mixture 1.5	Series 2	Based on 1.1, on a perfect particle size distribution
Mixture 1.6	Series 3	Based on mixture 1.3, now microsit was added
Mixture 1.7	Series 3	Based on 1.3, Fly ash replaced by Microsit
Mixture 1.7.1	Series 3	Based on 1.7, extra microsit, less cement
Mixture 1.8	Series 3	Based on 1.1, perfect particle size distribution, now with microsit
Mixture 1.10	Series 4	Based on 1.7, amount of water optimalized.

All these mixtures were tested in the concrete lab. For each mixture the required amount of Super Plasticiser was determined to give the mixture the perfect workability characteristics. From each mixture three prisms were made, besides we filled some small plastic boxes with concrete and mesh to study the permeability and the workability. The prisms were tested after 28 days and based on the results (see next section), the colour the workability and the density of the mixtures the best mixture for our canoes could be determined.

3.3. Analysis

This section concerns the analysis of the test results. All mixtures mentioned above have been tested. Based on the experiences in the concrete lab new mixtures were developed, making the proportioning of the mixtures an iterative process.

3.3.1. Workability and Colour

Two important indicators were the workability and the colour. The workability could be tested at the moment of casting and the colour during demoulding (the day after casting). Meaning that feedback concerning these indicators was available fast, making it possible to adjust the proportioning in a short time span.
During the first series the colour of the mixture was the main objective, two different pigments were added to the mixture of 2011, since this was also white mixture the colours were as bright as possible. The two different black pigments were used and the most black one was chosen, in this case HS 25235.

After the visit of ENCI series 1 were tested, at ENCI we obtained three new mixtures to test. The workability of these mixtures were not all that perfect. The mixtures with glasmehl felt sandy. This is exactly what we don't want. The mixture should be like clay and very sticky to the walls of the mould, but not to your hands. In order to determine whether glasmehl was useful the strength in combination with new tests on workability were necessary. Also for the other mixtures an iteration step was necessary. Therefore series 2 was developed.

During series 2 the particle size distribution was optimized, according to the described mix design method. These new tests gained a little more insight about the water demand of the mixture and the workability. After the Microsit was delivered another series of mixtures could be produced. Mixtures series 3 were designed, and because of the lack of workability mixture 1.7 turned out to be the best mixture. However, the density must be low and the strength must be high enough. Unfortunately it did not meet these goals to a proper extend.

3.3.2. Density

Since the addition of expanded glass in the 2009 mixture the density of the mixture decreased drastically. Since we as "BetonBrouwers" always want to improve ourselves this year the objective was to create a mixture with a density below 1000 kg/m^3. We discuss the possibilities for this during our visit to ENCI Rotterdam. The results of this workshop were clear: The strength of the 2011 mixture was around 30 N/mm^2. This strength is enough for a concrete canoe. In 2011 it turned out that not only the density is really important for the weight of a canoe, but more important even is the workability of a mixture. When the possibility is there that really thin walls can be constructed, much more can be gained on the weight than just by density.

Nevertheless, the goal this year was to keep the same workability and in the same time slightly decrease the density of 2011 which was 1255 kg/m^3. The density was tried to decrease by replacing some cement by microsit which has a lower density.

3.3.3. Strength

Because of the workability and the colour, several mixtures were not applicable for our canoes. Therefore only the remaining suitable mixtures are tested concerning their strength. Since the equipment at our University is not really made for testing flexural strength and is not working properly as a result of missing parts, the testing took place at the laboratory of Rokramix Enschede. The flexural strength was tested with a 3 point bending test. With the two remaining pieces of the prisms the compressive strength was tested.

The table below shows the density of each mixture and the flexural - and the compressive strength after 28 days of curing. It concerns the averages, the exact test results can be found in appendix B.

Mixture:	Density [kg/dm^3]*:	Flexural Strength [N/mm^2]:	Compressive Strength [N/mm^2]:
Mixture 1	-	-	-
Mixture 1.1	1.29	4.75	30.35
Mixture 1.2	1.26	4.71	28.78
Mixture 1.3	1.30	3.88	26.92
Mixture 1.4	1.32	3.22	35.60
Mixture 1.5	1.33	4.91	33.12
Mixture 1.6	1.23	3.91	24.61
Mixture 1.7	-	4.99	28.72
Mixture 1.7.1	1.21	4.91	32.91
Mixture 1.8	1.24	5.44	27.90
Mixture 1.10	1.19	5.23	29.65

Table 3.2: Density and average strength of the mixtures (measured).*

As can be seen in the table the mixtures all slightly differ from each other. All have a low density and the strength of all is around the 30 N/mm^2.

In order to test the collaboration between the concrete and reinforcing mesh, in 2009 plates were produced of +/- 5mm thick containing two layers of fibreglass mesh. In order to prevent disturbance at the edges, three slabs of 450mm x 150mm x 4mm were cut from each plate. These slabs would represent the walls of the canoe and were tested on elasticity at BAS bv. These plates turned out to be very flexible and therefore fulfil our requirements abundantly.

Since it requires a lot of effort and time to produce these slabs in combination with the large amount of mixtures this year, we argued if this test was necessary again. Because the reinforcement is similar to that of previous years and the concrete shows similar characteristics as that of last year, we expect that the concrete will show the same flexibility. Therefore it was decided not to put a lot of effort in testing the flexibility again.

3.3.4. Conclusion

This paragraph will draw a conclusion about the design of the concrete mixture. Our four main requirements were: Colour, Workability, Density and Strength. With an overall requirement that the concrete should not be permeable. Out of all these requirements mixture 1.10 was chosen because of the following reasons:

- **Colour:** The colours were good, since the basic mixture is black, but also a bright red colour was important, this was tested with the final mixture, and then it was approved to be good.
- **Workability:** The workability of this mixture was perfect, by adding the retarder the concrete was usable for a long time, very sticky to the walls of the mould, and it was possible to create very thin walls, which makes it possible to create very light canoes.
- **Density:** Since the goal of this year was also to the decrease the density of the concrete the Microsit was added. This resulted in a measured density of 1119 kg/m^3. Last year the density was much higher (1255 kg/m^3) and therefore this goal was reached.
- **Strength:** The strength of the mixture is ok to our requirements 29.65 N/mm^2, since we approximately need 30 N/mm^3.

Since the workability was ok, the colours were good, the density quite good, and the strength was ok in regard to the requirements. Mixture 1.10 was chosen as mixture. The exact composition of mixture 1.10 is shown in table 3.3 and figure 3.1.

Mixture 1.10:

Material:	Mass [kg]	Volume [dm^3]
CEM I 52.5R LA White	350.0	114.0
Microsit	160.0	64.3
Microsilica	50.0	21.5
Water	201.2	201.2
Liaver 0.1-0.3	257.1	265.1
Liaver 0.25-0.5	74.0	129.8
Liaver 0.5-1.0	70.1	146.1
GL 51	4.0	3.6
Pigment blck	17.5	17.5
Air	0.0	50.0
Total:	**1183.9**	**1000.0**

Additional information:	
Glenium 51:	1.1kg/m^3
w/c ratio:	0.57
w/b ratio:	0.36
w/p ratio:	0.36
Pigment:	5% cem. Mass
Natural air:	2%

Table 3.3: Mixture 1.10

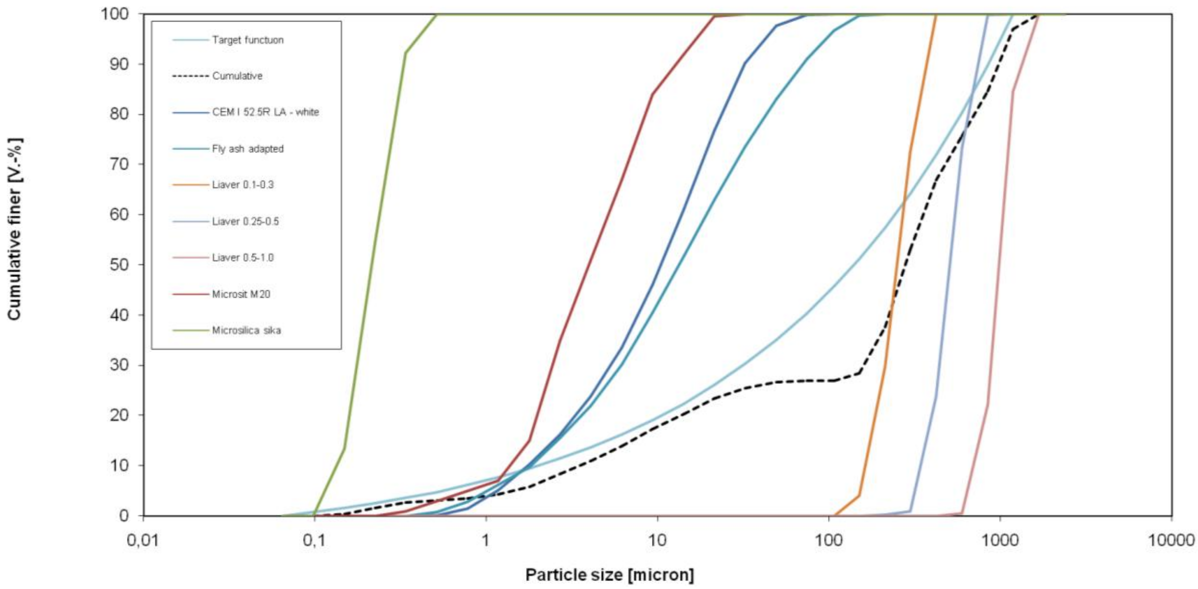


Figure 3.1: Particle Size Distribution of mixture 1.10

Sustainability

Another important matter these days is sustainability. Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. So besides the four main requirements as mentioned above, we also tried to make our concrete canoes as sustainable as possible.

The sustainability of our race canoes starts with the amount of concrete used. For our race canoes we only use 50litres of concrete and try to minimize the amount of waste. The other aspect of the sustainability of our canoes lies within the used ingredients. The most important ingredient in regard to the sustainability of our concrete is the cement. Since a big amount of heat is required to produce cement, cement has a high amount of embodied energy. As can been seen in table 3.3 our concrete has a low amount of cement, only 350kg/m^3.

In order to make the mixture more sustainable Microsit, a sieved fly ash is used. This fly ash is available in every desired grain size and thereby sustainable since it is one of the residues generated in combustion, the burning of waste. Another rest product which is used in the mixture is microlicia or silica fume, this is a rest product of the chip industry. Also the lightweight aggregates are sustainable, Liaver is made from recycled glass and thereby an ecological product. All materials together makes this mixture quite sustainable.

In addition to the sustainability of our race canoes, we also constructed a special canoe with recycled material. The details of this special canoe can be found in Construction Report BetonBrouwers 2012 - Part 2.

3.4. Highlighting reinforcement materials

The canoes are not only made out of concrete. To cope with all forces on our canoes, reinforcement is required. In this section we will highlight the reinforcement materials used in our canoes. To provide strength, stiffness and stability in our canoes, we reinforced them with steel cords and stucco-mesh.

3.4.1. Steel cords

In the length of the canoe we use pre-stretched steel cords. This is to provide the stiffness of our concrete. The two types of steel cords are:

- Steel cord 0.59+6x0.52, Ø4.4mm^2, F_{max} = 5160N
- Steel cord 0.66+6x0.59, Ø5.0mm^2, F_{max} = 7560N

The two upper steel cords are inside plastic tubes, which are placed in the edges of the canoe. In the front- and back end the steel cords are connected and stretched with an iron anchor plate.

3.4.2. Mesh

The canoe is reinforced with glass fiber reinforcement fabric. This 5x5 mm stucco-mesh fabric catches the tensions in the concrete. Glass fiber is a relatively light material: the weight is 75 gram per square meter. In order to test the tensile strength of the material we did several tests at the university laboratory (thanks to Dr. Vitaly Koissin).

To test the tensile strength we used strips from the mesh fabric as specimens, as visible in figure 3.7. These strips were placed one by one in special measurement equipment (figure 3.8).

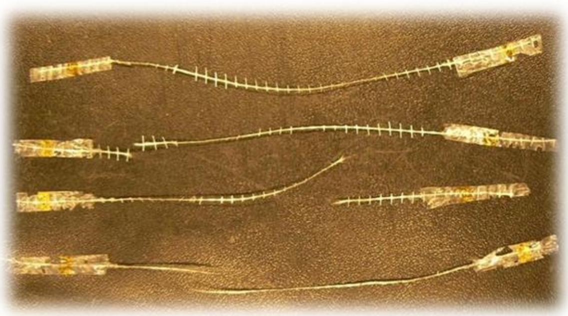


Figure 3.2: Specimens of mesh fabric

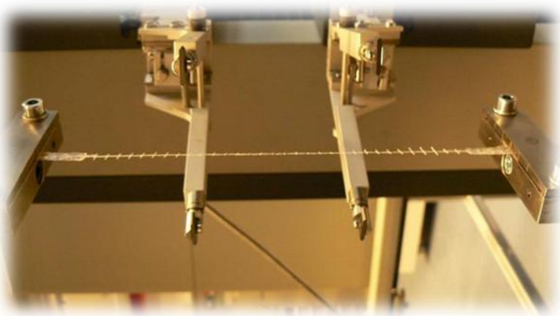


Figure 3.3: Testing the specimens

We tested eleven specimens. At the first three specimens the cross wires were removed (the lowest specimen in figure 3.2). The results are shown in figure C4 and table C1 in Appendix C. The three specimens without the cross wires do have significant lower tensile strengths. To determine the tensile strength, we calculate the mean and standard deviation of the eight specimens with cross wires.

$$\bar{F}_{0.2\%} = 68.9N$$
$$S(F) = 6.9N$$

In order to test the quality of the material it is possible to calculate the tensile strength in MPa. Therefore we have to know the surface of the cross section of the material. In figure 3.4 the cross section of one specimen is visible. The surface per wire is about 12 microns (figure 3.10).

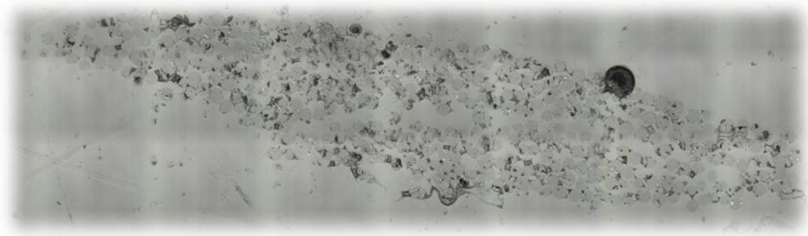


Figure 3.4: Cross section of a specimen

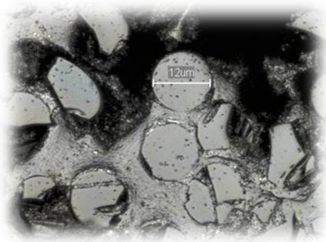


Figure 3.5: Closer look to cross section of a specimen

The total amount of wires per specimen is estimated at 360. Since the diameter of a wire is estimated at 12 microns, the surface is equal to about $360 \cdot (6 \cdot 10^{-6}\, m)^2 \cdot \pi = 40 \cdot 10^{-9}\, m^2$. When we divide the average tensile strength with this value, we get the tensile strength per square meter: $\frac{68.9N}{40 \cdot 10^{-9}\, m^2} = 1.7 \pm 0.2\, GPa$.

The normal tensile strength from E-glass fiber is about 2000 MPa [Azom.com] This indicates that our specimens are from a rather good quality.

3.5. Material Status

While the construction (reinforcement) and the concrete mixture are known, only the materials for the finishing touch remain. Because the canoes are not allowed to sink in case of breaking or capsizing, air chambers are needed. Therefore a big air balloon of 65 litres is used. Furthermore tubes are placed on the edges for aesthetics and safety (prevents scratches from sharp edges). Finally the name, sponsors and number are painted on the walls. In the table below (table 3.4) the material status of our canoes is given, in this table all used materials and their specification are mentioned.

Element:	Material:	Specification:	Amount:	Total:
Lightweight Concrete	CEM I 52.5R LA White	0.35 kg/l		17.5 kg
	Microsit	0.16 kg/l		8.0 kg
	Microsilica	0.050 kg/l		2.5 kg
	Water	0.20 kg/l		10.6 kg
	Liaver 0.1-0.3	0.26 kg/l	50 l	12.9 kg
	Liaver 0.25-0.5	0.07 kg/l		3.7 kg
	Liaver 0.5-1.0	0.07 kg/l		3.5 kg
	GL 51	0.004 kg/l		0,2 kg
	Pigment blck	0.02 kg/l		0,9 kg
	Air	0.0 kg/l		0,0 kg
Reinforcement	Steel cord 0.59+6x0.52 Ø=4.40 mm^2 MBL=5016N	1140 N/mm^2	18m	18m
	Steel cord 0.66+6x0.59 Ø=5.0 mm^2 MBL=7560N	1540N/mm^2	12m	12m
	Stucco-Mesh	4x4mm	2 layers	13.5 m^2
	Anchor plate	250X100mm	2 pcs	2 pcs
	Anchor connection ironware	-	4 pcs	4 pcs
	Tube for cord	4x6 mm	2x 6 m	12 m
Air chambers	Air bags	65l	1pcs	65l
	Connection ironware	-	4 pcs	4pcs
	D shackle	-	4 pcs	4 pcs
Completion	Paint	Dark blue	1 l	1l
	Tube (edge protection)	-	2 pcs	12 m
	Seating foam	-	2 pcs	2 pcs

Table 3.4: Material Status Concrete Canoes

Part 4

A process description of construction year 2012

In this fourth part of the report the focus is on the process of construction year 2012. From a nice design on a computer screen to a beautiful concrete canoe requires a lot of blood, sweat and sometimes even tears. Things sometimes seem to work in theory, but practice can prove otherwise. That's why it is important to be creative, flexible and always looking for solutions. This part gives a clear insight in the construction process of our canoes and everything that comes along with it. But only building a beautiful concrete canoe doesn't guarantee victory during the race. That's why also training plays an important role in our way to success!

4.1 In preparation of construction

After the victories our last design brought us we thought it was time to improve the design even further. With the knowledge of previous years, in 2011 our head of design worked on a new design for a new canoe. After many hours of work the perfect design was obtained. A new design meant that a new mould had to be build. Thereby we wanted to cast a concrete red horse in the hull of our canoes, therefore a template had to be made.

4.1.1 Building a mould

The last time we had to build a mould we used wood to do this. A lot of the building we had to do ourselves and this had the problem that little inaccuracies were made. This resulted in small bumps in the mould and eventually the canoes. Our goal was to prevent this from happening in the new mould. The easiest way to prevent this was to get a specialized company to build or mould, but unfortunately this was too expensive. This meant that we still had to do a lot of the work ourselves.

After a few brainstorming sessions the plan for making the new mould was finished. Instead of wood we used foam to make the model. Out of foam plates a milling company cut 60 sections with a width of 10 centimetres each. All these sections were then placed on a metal bar and attached to each other with two component glue. As expected the glue led to an increase of the canoe length which meant the canoe would exceed the permitted length of six meters. Because of this we decided to cut one of the layers in half so that the model would be less than six meters long. Now all the sections were stuck to each other the shaping of the canoe could start. To prevent small inaccuracies pieces of sandpaper were taped on long beams of timber. This way it was impossible to sandpaper only a small part of the model. To get a smooth surface different fractions of sandpaper were used.

The next step in the process was brushing a liquid filler on the model. The filler was put on the model so that later on the model wouldn't suck up all the polyester filler which needed to be on the outside of the model. This polyester filler was also used to fill any gaps between two sections. In total 8 litres of liquid filler and 1,5 litres of polyester filler were used. All the work that we could do in our own workshop till than was finished and it was time to put the model in the trailer of a glider and transport it to Beek and Donk. Beek and Donk is a place in Noord-Brabant were Ascom polyester is located. This is the same company that helped us build the mould in 2009 and the offered to help us again.

In total we worked three days in Beek and Donk to finish the mould. The first day consisted mostly out of sandpapering the model. Because the polyester layer was put on the model all of the sandpapering had to be redone. This was done with three different fractions, 80, 120 and 240. Before switching to a smaller fraction a special powder was put on the model. The function of the powder was to indicate on which places there were dents. This way we knew were to sandpaper a bit more. If the dents were too big putty was used to close the gaps. On the end of the day the model was as smooth as a baby buttocks. Before returning to Enschede the model was discomposed of dust and lacquered with double coat.

After the double coat was dried the second day of hard work at Ascom polyester could start. This day the model had to be waxed. This had to be done nine times. The wax had to made sure the model could be separated from the mould easily. After the waxing was done a special gel coat was put on the model. The gel coat ensured that the mould can be used multiple times and functions as a protective layer. We also put plates made of pvc on the end of the canoe. The plates make it possible to make the mould so that both sides can be opened separately.

The last day at Ascom polyester meant we finaly could start working on the mould. The model was first covered with polyester resin and then with fiberglass. This procedure was repeated four times. After this the resin had dried the edges of the mould were sawn off en the offside of the mould was sandpapered. This was done so that later on nobody could cut his hands on any fiberglass that was still on the outside of the mould. After sandpapering the mould it was ready to transport back to Enschede. Back in Enschede the last thing that needed to be done was separate the mould from the model. After a few minutes of struggling we were able to get the mould loose, unfortunately this also meant the end of the model because it broke in half.

4.1.2 How to cast decoration in the hull

This year we wanted to cast a decoration in the hull of our canoe. Previous year we obtained some knowledge how to work with different colors in one canoe. This year however, the shape of the decoration is much more complex. We decided to make a template. First this template was made out of thin sheet metal, but eventually we decided to produce the templates out of Perspex. Before casting the canoes this new technique of cast decoration was tested in the concrete lab. The template was put on a plate, it was filled with red concrete and the surrounding was made from black concrete, just like it has to become in the canoes. The result was very nice and we felt ready to apply this method in our canoes. However there was a big difference between the test we performed in the lab and the actual casting in the canoe. In the lab everything was done on a horizontal plate and with enough space, the casting in the canoe had to be done in a vertical position and the small section of the canoe, giving limited space for maneuver.

4.2 Constructing beauties

Above it is explained how the new mould is constructed. In this section it is explained how the concrete mixture in combination with the reinforcement and the new mould result in beautiful concrete canoes. The following points are important for successful casting: Adequate formwork quality, Concrete workability, Casting technique and Curing conditions. Throughout the description of the casting process below, these points can be recognized.

At the start of creating a concrete canoe stands a cleaned mould. This clean mould is placed on a steel framework, which forms the work platform during construction. The idea of the mould is that it will give the concrete the right shape and that the concrete canoe can be taken out of it. When we have the clean mould in place it is time for putting the templates in the mould. Next, the demoulding oil is sprayed onto the mould. In the mould, on the bottom, three steel cords are placed, intended for pre-stressing. One cord is going through the middle while the other two cords run through the corners of the bottom. Besides three cords in longitudinal direction, also four cords in cross direction were placed. These cords are intended to make the cracks in the longitudinal direction smaller or even disappear. The cords were hold in position with the help of little holes in the mould and the use of iron wire. After placing the cords, they were put on tension (not with the final force because the mesh has to be placed underneath the cords). After this it is almost time for starting the casting, but first we need to try rub the surface in with grease and on the other hand to make the cords grease free. This for obvious reasons.

When we got the mould in the condition of a greased surface and ungreased cords it’s time for casting. This means that all materials can be weighted in the right proportions and the mixture can be made. First the dry materials are put into the mixer. We use a batch mixer, type forced action mixer, whereby the concrete is mixed by paddles rotating through the concrete. When the dry materials are mixed properly the liquids are added. This created a stiff mix of materials. To make obtain the right workability, Super Plasticizer (SP) is added. The process of adding the SP is a delicate matter. A little bit too much turns the mixture in a soup and is far from ideal, but a little bit too less makes the mixture to dry and not workable either. But, when the right consistency if found, the mixture is ready to be processed.



The first step in casting is casting the decoration: the red horst in de stern of the canoe. When the red concrete is in place the regular casting process can start. For a strong and flexible canoe the section of the canoe will be layered as follows; a thin layer concrete – mesh (underneath the cords) – another layer of concrete – mesh again (above the cords) – and eventually the last layer of concrete. This process will go step by step starting in the back and working towards the front of the canoe. The challenge with this process is that it needs a constant flow of concrete, because the layer concrete won't dry out in such degree that it won't adhere with the next one. Extra focus is needed on the place of the horse, the template may not move because of rough handling and the black and red concrete may not mix at the outside of the canoes (the first layer).



As told earlier in this report we used five cords per canoe. The remaining two cords are placed on the top of the walls of the canoe during the process. When the concrete had enough time to harden these cords are stressed afterwards. While working from back to the front four ribs were created at the location where the cords in cross direction are located. After reaching the front of the canoe the cords in the longitude direction can be put on the right tension. This was done by pushing the framework apart with the use of two jacks. After a check if everything stayed in place after stressing the cords and scratch away the surplus concrete, the canoe was considered finished. When all this is done, it's time to create an ideal atmosphere for the concrete to cure, this means creating a high humidity. This was done by wrap the concrete with paper and spray this paper wet. Finally a foil was put over the mould sealing the canoe. During wrapping the canoe with paper some delicious snacks were fried. Meaning that after the work was done everybody could enjoy a cold Grolsch beer and the snacks from our very own Fry King.




After at least one day of hardening the canoe could be demoulded. To do this the prestressed cords have be cut at the point where they exit the mould. The next step is to turn the mould around and remove all steel wire coming out of the mould. When all connection are removed, the mould can be bended outwards and lifted, leaving a beautiful concrete canoe on the floor. At this moment the two upper cords can be post stressed. This is done by placing two metal plates on the bow and stern of the canoe and attach the cords to them with the use of a bold. By turning the bolds the cords gets tensioned and the canoe is compressed. The tension is gradually increased until the required tension is reached. By increasing the tension in several steps the concrete can ‘get used to’ the new forces acting on it. In the meanwhile it is important that the canoe is cured properly. Meaning that the canoe is covered in foil and once in a while is sprayed with water.

In the last stage of the construction, the names, the sponsors and start numbers were painted onto the canoes. On top of the walls tubes are placed as protection against sharp edges and because of the aesthetics. At the wall some bolds are constructed in order to attach the air chambers, these air chambers consist of large balloons. Now the canoes themselves are finished and ready for the battle. But, we are not finished yet. There are still some things that have to be taken care of. The first thing is to maintain the canoe bearers. In these bearers the canoes can be transported and stored safely and on site we can carry them easily without damaging them. The second thing that we want to construct are some foam seats for the canoeists to sit on and to distribute the forces of the canoeists more equally towards the bottom.

4.3 How to handle a paddle

During the season, a second important factor in the success of the BetonBrouwers is also carried out. The canoes provide roughly 50% of the chances of winning the BKR, the other 50% is achieved by training. To ensure that the training is effective, the BetonBrouwers train all year-round. There are two parts that can be separated: the “warm season” and the “cold season”.

4.3.1 Cold season

During the winter period (i.e. short days, cold weather) training on the Twente canal is not possible (prohibited). That is why the training for the BKR is relocated to the indoor swimming pool on the University of Twente campus. During this period, a lot of attention goes to peddling technique and cardio. The training consists of three separate parts: peddling, swimming and fitness exercises. This mixture of different elements of training makes the cold season a very effective training season.

4.3.2 Warm season

At the start of spring the swimming pool is exchanged by the Twente Canal. In aluminium Canadian canoes the BetonBrouwers encounter the Twente Canal. For the new paddlers this is the moment of some important lessons:

- Lesson 1: When on the water, never lose your paddle! Our motto: my paddle, without me, is useless. Without my paddle, I’m useless.
- Lesson 2: Keep your balance, don’t fall into the water. Despite the Canadian canoes are relatively stable, it is important to keep your balance. Especially when it is cold, the risk of falling into the water should be avoided at all costs. Thereby the water doesn’t looks very attractive to swim in...
- Lesson 3: Avoid getting close to fishermen. It isn’t a pleasure when a fishermen gets you on his hook.

With these lessons in mind the BetonBrouwers paddle the Twente Canal, practicing sprints, endurance races, turning and accelerate. To get used to the feeling of the concrete canoe, one of the canoes of 2010, ‘De Slachttand’, was transported to the water sports complex. This gave us the possibility to train in a concrete canoe preceding on the races in Eindhoven.

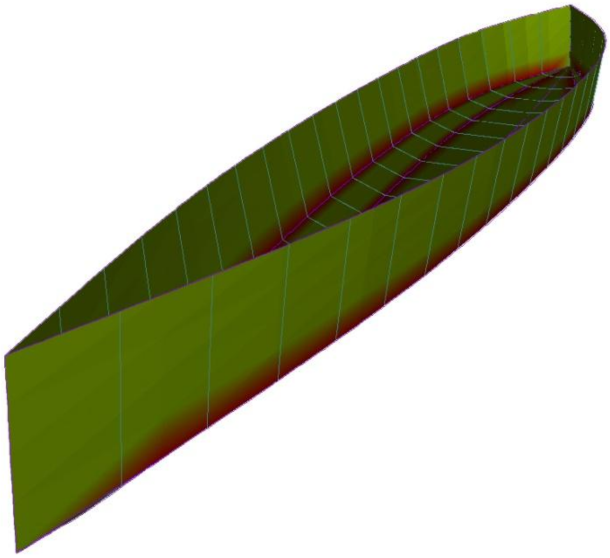
It is important to train outside, because weather conditions (i.e. wind, rain, waves) can make a big difference during the BKR. To get familiar with different weather conditions and the behaviour of a canoe on open water, the training is intensified as the BKR approaches.

The “training grounds” consist of a manmade canal that is normally used for large barges. It is a wide canal with a long straight part between the Hengelo sluice complex and the Enschede harbour. During a normal training, a distance of about 7 kilometres is covered. At the start of the ‘warm’ season, the correct peddling technique is an important aspect. A good basis is required before proceeding to sprint and slalom exercises. During a training, the ‘normal’ peddling is alternated with short sprints (200-400 meters) and tight turns, this to simulate the race elements of the BKR.

A few weeks before the BKR, a tight schedule is created to maximize the training effect. Hereby, a good mixture of experienced and less experienced peddlers is ensured every training session. This greatly enhances the training effect on the participants.

Concluding

In the first part of this report we said that only the real diehard Civil Engineering students with a heart of concrete, loads of motivation and a lot of persistence can become a BetonBrouwer. This certainly has proven to be true. If we look back on what we have reached in the last eight months within the scarce spare time of just ten students, it is really something to be very proud of and shows the loads of motivation and dedication. So without questioning we can conclude that building concrete canoes is a very time consuming hobby, but that a lot of satisfaction can be gained. And although no study credits can be gained, it is a real addition to the standard curriculum while it provides a perfect learning environment in regard of putting theory into practice, creative thinking and always look for solutions.



The goal this year was to optimise the surface of the canoes and the concrete mixture, with the mould and design of 2011 as basis. The mould has been treated in such a way that the outer surface of our canoes is smoother. Besides that, integrate a concrete Twents Ros in the hull has put ourselves for a challenge. Though we were able to deal with this. Also the experiment of designing and constructing a concrete canoe that can be folded and a canoe out of recycled canoes is achieved.

During the Concrete Canoe Challenge we will know if the new canoes performs better than that of the previous years. At least the walls are smoother, the canoes are lighter and the paddlers are better trained than before. It is a very satisfying thought that when we look at the canoe, we can say that everything from the design until the mould and from the first batch of concrete until the finishing touch is done by ourselves. No matter if it becomes a great success or a big failure, it absolutely was a wonderful project to work on! But of course we hope to put a crown on our work with some heroic and memorable victories and return with some nice Cups to Enschede.

Finally we want to outline that it was quite a challenge to put all the obtained knowledge and experience into a proper construction report. Hopefully it has given a clear view on how our canoes have been constructed. We hope you have enjoyed reading this construction report.

Literature

Azom.com (2011). *E-glass fibre.*(http://www.azom.com/Details.asp?ArticleID=764 , 8 april 2011).

BetonBrouwers (2006). *Brouwsel onder spanning.* Studievereniging ConcepT, Universiteit Twente.

BetonBrouwers (2010). *How it's made: concrete canoes.* Studievereniging ConcepT, Universiteit Twente.

Brouwers, H.J.H. and Radix, H.J. (2005), *Self-compacting concrete: theoretical and experimental study*. Cement and Concrete Research 35, pp 2116-2136, Erratum, ibid 37, p. 1376 (2007).

ENCI (2006). *Wit portlandcement – CEM I*. Heidelberg Cement Group.

Hartsuijker, C. (2001). *Toegepaste Mechanica deel 2: Spanningen, vervormingen, verplaatsingen.* Den Haag: Academic Service.

Hunger, M. (2010). *An Integral Design Concept for Ecological Self-Compacting Concrete.* Technische Universiteit Eindhoven.

Hüsken, G. and Brouwers, H.J.H. (2008). *Earth-moist concrete: application of a new mix design concept*. Cement and Concrete Research, vol. 38, pp. 1246-1259.

Krikhaar, H.M.M. (2010). *Betonpocket*. ENCI, Mebin en Sagrex. ENCI B.V.

Liaver (2010). *Datenblatt Liaver*

Madison Concrete Canoe Team (2008). *Design Papers.* University of Wisconsin. Obtained on 20 November 2008 from http://www.engr.wisc.edu/studentorgs/canoe/Design%20Papers/Design_Papers.htm

Murphy, M.L. de, Lissenden, C. & Xiao, C. (2009). *Technology Evaluation on Characterization of the Air Void System in Concrete*. Pennsylvania Transport Institute

Norwegian University of Science and Technology (2009). *Concrete Technology 1*. Trondheim. Stefan Jacobsen.

Vitro Minerals (2009). *Portland Cement and Pozzolans, Technical Background for the Effective Use of VCAS Pozzolans in Portland Cement Concrete.* Retrieved on 25-01-2010 from http://www.vitrominerals.com/general-pozzolan-technical-information.pdf

Winters, J. (2005). *The Shape of the Canoe – Designing Canoes and Kayaks*. Retrieved at 10-01-2009 from: http://www.greenval.com/jwinters.html

Appendices

Background information

In this section of the report you will find the appendices. These appendices provide some background information for the people interested. First of all the contact information of Study Association ConcepT, the Chairman and the Event Manager of the committee is given. In the second appendix the background information behind the concrete mixtures is given. Third some extra information about highlighted materials will be given.

Appendix A: Contact Information

In this appendix the contact information is provided of Study Association ConcepT, our Chairman (and team captain), Ynze Goinga, and Event Manager Rik Goossens.

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Appendix B : In search of the optimal Mixture

This appendix contains more detailed information concerning the different mixtures that have been composed and tested. First the composition of all mixtures is shown, after which the test results are given.

Compositions:

Mixture 1

Material:	Mass [kg]	Volume [dm^3]
CEM I 52.5R LA White	550.3	179.3
Liaver 0.1-0.3	121.1	201.8
Liaver 0.25-0.5	53.0	98.2
Liaver 0.5-1.0	50.0	111.2
SikaAer	8.0	40.0
Pigment	27.5	7.0
Water	206.7	210.2
GL 51	0.0	0.0
Retarder	1.7	1.7
LPS A94	0.7	0.7
Air	0.0	150.0
Total:	**1018.5**	**1000.0**

Additional information:	
Glenium 51:	1.3kg/m^3
w/c ratio:	0.38
w/b ratio:	0.38
w/p ratio:	0.36
Pigment:	5% cem. mass
Natural air:	2%
Entrained air:	13%

Mixture 1.1

Material	Supplier	Mass [kg]	Density [kg/dm3]	Volume [dm^3]
CEM I 52.5R LA - white	CBR	350,0	3,07	114,0
Fly ash		100,0	2,20	45,5
Glassmehl		80,0	0,80	100,0
Microsilica (Cembinder 8)		150,0	1,40	107,1
Solid content		75,0	2,33	32,2
Water content		75,0	1,00	75,0
Water		135,0	1,00	135,0
Liaver 0.1-0.3	Liaver	129,4	0,60	215,7
Liaver 0.25-0.5	Liaver	57,1	0,54	105,7
Liaver 0.5-1.0	Liaver	53,5	0,45	118,9
Superplasticizer		4,0	1,10	3,6
Air entrainer				
Pigment black		17,5	3,90	4,5
Air				50,0
Total		**1076,5**		**1000,0**

Mixture 1.2

Material	Supplier	Mass [kg]	Density [kg/dm3]	Volume [dm^3]
CEM I 52.5R LA - white	CBR	350,0	3,07	114,0
Fly ash		0,0	2,20	0,0
Glassmehl		150,0	0,80	187,5
Microsilica (Cembinder 8)		150,0	1,40	107,1
Solid content		75,0	2,33	32,2
Water content		75,0	1,00	75,0
Water		95,0	1,00	95,0
Liaver 0.1-0.3	Liaver	128,8	0,60	214,7
Liaver 0.25-0.5	Liaver	56,8	0,54	105,2
Liaver 0.5-1.0	Liaver	53,2	0,45	118,3
Superplasticizer		4,0	1,10	3,6
Air entrainer				
Pigment black		17,5	3,90	4,5
Air				50,0
Total		**1005,4**		**1000,0**

Mixture 1.3

Material	Supplier	Mass [kg]	Density [kg/dm3]	Volume [dm^3]
CEM I 52.5R LA - white	CBR	350,0	3,07	114,0
Fly ash		200,0	2,20	90,9
Glassmehl		0,0	0,80	0,0
Microsilica (Cembinder 8)		150,0	1,40	107,1
Solid content		75,0	2,33	32,2
Water content		75,0	1,00	75,0
Water		175,0	1,00	175,0
Liaver 0.1-0.3	Liaver	133,7	0,60	222,9
Liaver 0.25-0.5	Liaver	58,9	0,54	109,2
Liaver 0.5-1.0	Liaver	55,3	0,45	122,8
Superplasticizer		4,0	1,10	3,6
Air entrainer				
Pigment black		17,5	3,90	4,5
Air				50,0
Total		**1144,4**		**1000,0**

Mixture 1.4

Material	Supplier	Mass [kg]	Density [kg/dm3]	Volume [dm^3]
CEM I 52.5R LA - white	CBR	420,0	3,07	136,8
Fly ash		0,0	2,20	0,0
Glassmehl		100,0	0,80	125,0
Microsilica (Cembinder 8)		200,0	1,40	142,9
Solid content		100,0	2,33	42,9
Water content		100,0	1,00	100,0
Water (w/c ratio)		200,0	1,00	200,0
real water		100,0	1,00	100,0
Liaver 0.1-0.3	Liaver	171,0	0,80	213,8
Liaver 0.25-0.5	Liaver	56,5	0,54	104,7
Liaver 0.5-1.0	Liaver	53,0	0,45	117,8
Superplasticizer		4,0	1,10	3,6
Air entrainer				
Pigment black		21,0	3,90	5,4
Air				50,0
Total		**1125,6**		**1000,0**

Mixture 1.5

Material	Supplier	Mass [kg]	Density [kg/dm3]	Volume [dm^3]
CEM I 52.5R LA - white	CBR	350,0	3,07	114,0
Fly ash		150,0	2,20	68,2
Glassmehl		80,0	0,80	100,0
Microsilica (Cembinder 8)		100,0	1,40	71,4
Solid content		50,0	2,33	21,5
Water content		50,0	1,00	50,0
Water		165,0	1,00	165,0
real water		115,0	1,00	115,0
Liaver 0.1-0.3	Liaver	165,9	0,80	207,4
Liaver 0.25-0.5	Liaver	54,9	0,54	101,6
Liaver 0.5-1.0	Liaver	51,4	0,45	114,3
Superplasticizer		4,0	1,10	3,6
Air entrainer				
Pigment black		17,5	3,90	4,5
Air				50,0
Total		**1088,7**		**1000,0**

Mixture 1.6

Material	Supplier	Mass [kg]	Density [kg/dm3]	Volume [dm^3]
CEM I 52.5R LA - white	CBR	350,0	3,07	114,0
Fly ash		150,0	2,40	62,5
Microsit		60,0	2,49	24,1
Microsilica (Cembinder 8)		0,0	1,40	0,0
Solid content		0,0	2,33	0,0
Water content		0,0	1,00	0,0
Water		224,0	1,00	224,0
Liaver 0.1-0.3	Liaver	152,1	0,60	253,5
Liaver 0.25-0.5	Liaver	67,0	0,54	124,1
Liaver 0.5-1.0	Liaver	62,8	0,45	139,7
Superplasticizer		4,0	1,10	3,6
Air entrainer				
Pigment black		17,5	3,90	4,5
Air				50,0
Total		**1087,5**		**1000,0**

Mixture 1.7

Material	Supplier	Mass [kg]	Density [kg/dm3]	Volume [dm^3]
CEM I 52.5R LA - white	CBR	350,0	3,07	114,0
Fly ash		0,0	2,40	0,0
Microsit		150,0	2,49	60,2
Microsilica sika		50,0	2,33	21,5
Water		181,2	1,00	181,2
Liaver 0.1-0.3	Liaver	166,1	0,60	276,8
Liaver 0.25-0.5	Liaver	73,2	0,54	135,6
Liaver 0.5-1.0	Liaver	68,6	0,45	152,5
Superplasticizer		4,0	1,10	3,6
Air entrainer				
Pigment black		17,5	3,90	4,5
Air				50,0
Total		**1060,7**		**1000,0**

Mixture 1.7.1

Material	Supplier	Mass [kg]	Density [kg/dm3]	Volume [dm^3]
CEM I 52.5R LA - white	CBR	300,0	3,07	97,7
Fly ash		0,0	2,40	0,0
Microsit		200,0	2,49	80,3
Microsilica sika		50,0	2,33	21,5
Water		232,0	1,00	232,0
Liaver 0.1-0.3	Liaver	242,9	0,97	250,4
Liaver 0.25-0.5	Liaver	69,9	0,57	122,6
Liaver 0.5-1.0	Liaver	66,2	0,48	138,0
Superplasticizer		4,0	1,10	3,6
Air entrainer				
Pigment black		15,0	3,90	3,8
Air				50,0
Total		**1180,0**		**1000,0**

Mixture 1.8

Material	Supplier	Mass [kg]	Density [kg/dm3]	Volume [dm^3]
CEM I 52.5R LA - white	CBR	350,0	3,07	114,0
Fly ash		0,0	2,40	0,0
Microsit		150,0	2,49	60,2
Glasmehl		80,0	0,90	88,9
Microsilica sika		70,0	2,33	30,0
Water		239,0	1,00	239,0
Liaver 0.1-0.3	Liaver	120,5	0,60	200,8
Liaver 0.25-0.5	Liaver	53,1	0,54	98,3
Liaver 0.5-1.0	Liaver	49,8	0,45	110,6
Superplasticizer		4,0	1,10	3,6
Air entrainer				
Pigment black		17,5	3,90	4,5
Air				50,0
Total		**1133,8**		**1000,0**

Mixture 1.10

Material	Supplier	Mass [kg]	Density [kg/dm3]	Volume [dm^3]
CEM I 52.5R LA - white	CBR	350,0	3,07	114,0
Fly ash		0,0	2,40	0,0
Microsit		160,0	2,49	64,3
Microsilica sika		50,0	2,33	21,5
Water		201,2	1,00	201,2
Liaver 0.1-0.3	Liaver	257,1	0,97	265,1
Liaver 0.25-0.5	Liaver	74,0	0,57	129,8
Liaver 0.5-1.0	Liaver	70,1	0,48	146,1
Superplasticizer		4,0	1,10	3,6
Air entrainer				
Pigment black		17,5	3,90	4,5
Air				50,0
Total		**1183,9**		**1000,0**

Test Results

In the tables below the test results concerning the Flexural and the Compressive Strength are given for each composed mixture.

Mix name:	Prism	Data cast	Date test	Age [days]	Flexural strength [N/mm2]	Compressive strength 1	Compressive strength 2	Density [kg/l]	Average Flexural	Average Comp.	Remarks
1.1	1.1.1	22-01-12	31-01-12	9	4,56	30,21	29,98	1,29	4,75	30,35	
	1.1.2	22-01-12	31-01-12	9	5,34	30,68	29,20				
	1.1.3	22-01-12	31-01-12	9	4,36	31,48	30,55				
1.2	1.2.1	22-01-12	31-01-12	9	5,09	27,10	29,20	1,26	4,71	28,78	
	1.2.2	22-01-12	31-01-12	9	5,20	30,45	29,24				
	1.2.3	22-01-12	31-01-12	9	3,85	28,92	27,78				
1.3	1.3.1	22-01-12	31-01-12	9	3,36	27,01	26,47	1,30	3,88	26,92	bad compaction
	1.3.2	22-01-12	31-01-12	9	4,21	28,45	25,34				
	1.3.3	22-01-12	31-01-12	9	4,08	27,87	26,39				
1.4	1.4.1	1-02-12	7-02-12	6	2,99	28,90	28,90	1,32	3,22	35,60	
	1.4.2	1-02-12	29-02-12	28	3,51	35,36	35,68				
	1.4.3	1-02-12	29-02-12	28	3,16	35,89	35,48				
1.5	1.5.1	1-02-12	7-02-12	6	3,84	26,90	26,90	1,33	4,91	33,12	
	1.5.2	1-02-12	29-02-12	28	5,38	35,92	35,61				
	1.5.3	1-02-12	29-02-12	28	5,50	30,42	30,51				
1.6	1.6.1	16-02-12	23-02-12	7	3,62	23,22	22,74	1,23	3,91	24,61	
	1.6.2	16-02-12	15-03-12	28	2,83	19,28	24,59				
	1.6.3	16-02-12	15-03-12	28	5,28	27,94	26,64				
1.7	1.7.1	16-02-12	23-02-12	7	5,21	28,52	29,04	-	4,99	28,72	
	1.7.2	16-02-12	15-03-12	28	5,20	30,78	28,47				
	1.7.3	16-02-12	15-03-12	28	4,57	27,87	27,77				
1.7.1	1.7.1.1	16-02-12	23-02-12	7	3,89	22,94	22,42	1,21	4,91	32,91	
	1.7.1.2	16-02-12	15-03-12	28	5,31	32,96	33,15				
	1.7.1.3	16-02-12	15-03-12	28	5,52	33,28	32,25				
1.8	1.8.1	16-02-12	23-02-12	7	4,79	23,38	24,08	1,24	5,44	27,90	
	1.8.2	16-02-12	15-03-12	28	5,81	25,35	24,38				
	1.8.3	16-02-12	15-03-12	28	5,71	30,65	31,22				
1.10	1.10.1	24-02-12	23-03-12	28	5,21	29,97	28,47	1,19	5,23	29,65	
	1.10.2	24-02-12	23-03-12	28	5,24	30,12	28,95				
	1.10.3	24-02-12	23-03-12	28	5,23	30,78	29,58				

Appendix C: Highlighted materials

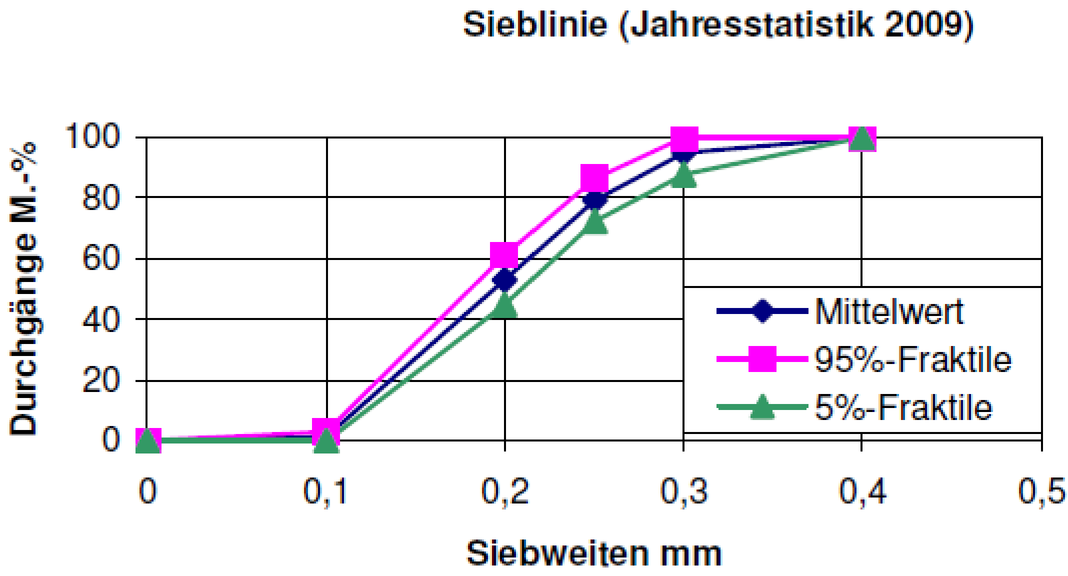


Figure C1: Sieve curve Liaver 0.1-0.3 [Source: Datenblatt Liaver, 2010]

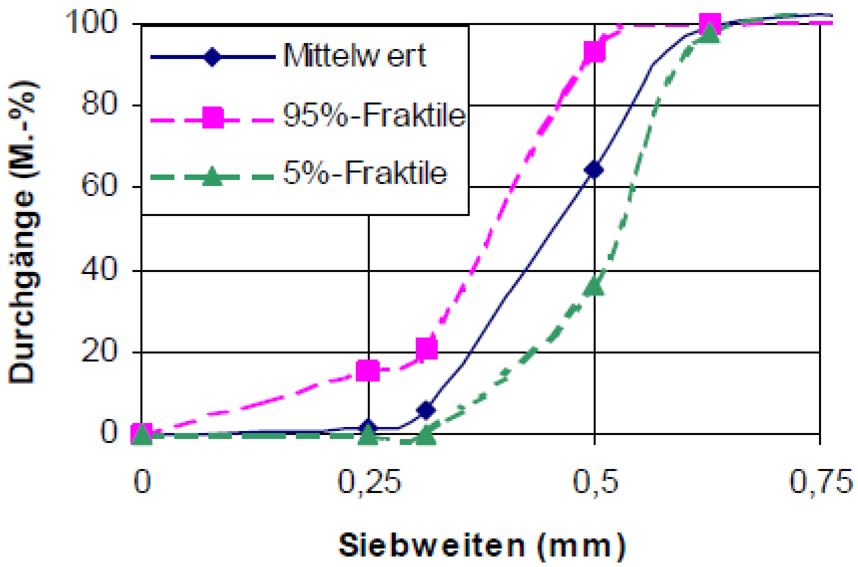


Figure C2: Sieve curve Liaver 0.25-0.5 [Source: Datenblatt Liaver, 2010]

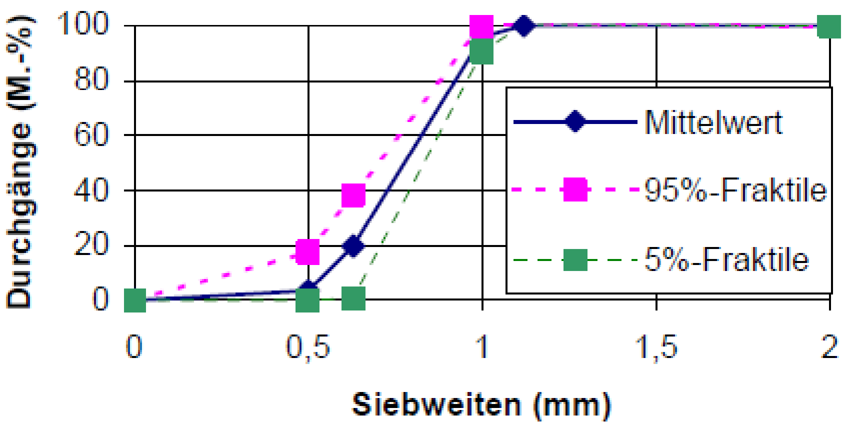


Figure C3: Sieve curve Liaver 0.5-1.0 [Source: Datenblatt Liaver, 2010]

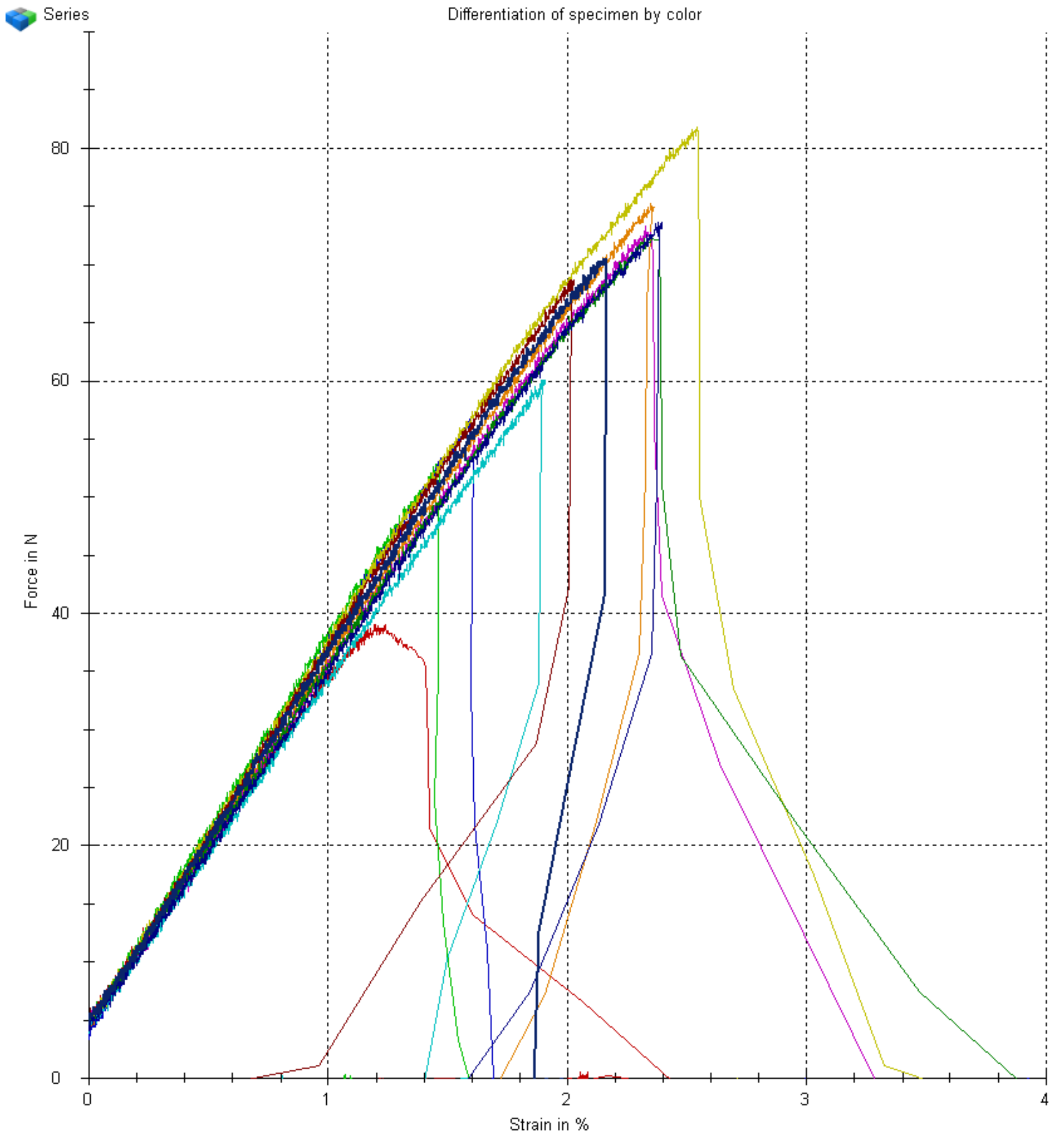


Figure C4: Visualization of specimens measurement results

Nr	Clock time	Date/Clock time	Emod GPa	F at 0.2% plastic strain N	Fmax N	dL(plast.) at Fmax mm
1	4:42:03 PM	3/21/2011 4:42:03 PM	293	38.0	39.0	0.1
2	4:51:41 PM	3/21/2011 4:51:41 PM	314	46.4	53.3	-0.0
3	4:57:17 PM	3/21/2011 4:57:17 PM	319	50.7	56.7	0.0
4	5:02:57 PM	3/21/2011 5:02:57 PM	300	72.0	75.2	0.1
5	5:09:47 PM	3/21/2011 5:09:47 PM	297	71.3	73.3	0.1
6	5:15:56 PM	3/21/2011 5:15:56 PM	288	55.2	60.0	0.0
7	5:20:46 PM	3/21/2011 5:20:46 PM	321	78.3	81.8	0.2
8	5:25:52 PM	3/21/2011 5:25:52 PM	312	63.7	68.7	0.0
9	5:38:53 PM	3/21/2011 5:38:53 PM	294	71.8	72.6	0.1
10	5:44:05 PM	3/21/2011 5:44:05 PM	295	71.6	73.6	0.1
11	5:51:06 PM	3/21/2011 5:51:06 PM	306	67.4	70.5	0.1

Table C1: Specimens measurement results

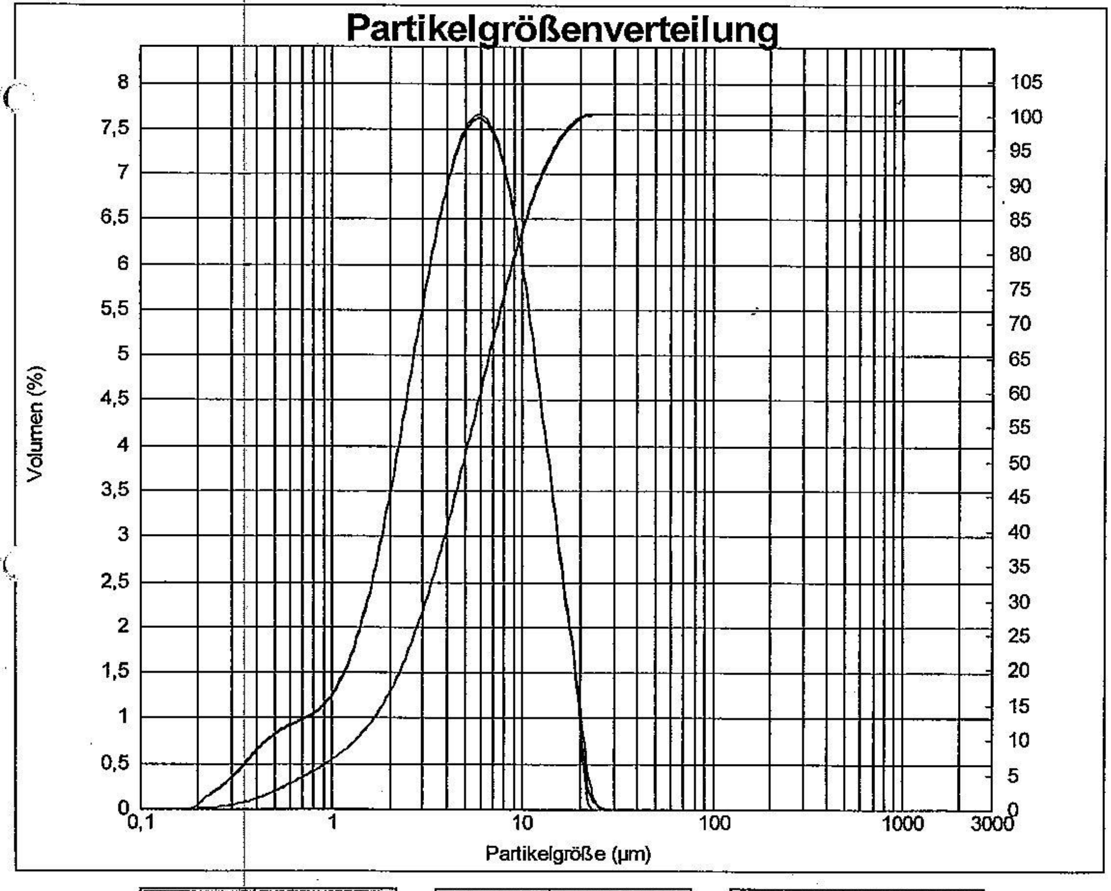
BauMineral
KraftWerkstoffe

Analyse Report

Probenname: Microsit M20 vom 08.02.2012 (0200/12) - Mittelwert
Gemessen: Donnerstag, 9. Februar 2012 14:13:14 **Bediener:** Reschka

Partikel RI: 1,520 **Absorption:** 0,1 **Abschattung:** 11,73 %
Meßbereich: 0,020 bis 2000,000 µm **Fit(gewichtet):** 0,752 %

Prozentsatz über 5,00 µm: 49,57% **Prozentsatz über 10,00 µm: 16,91%**
Prozentsatz über 20,00 µm: 0,45% **Prozentsatz über 50,00 µm: 0,00%**
Prozentsatz über 90,00 µm: 0,00% **D(0,50): 4,96 µm** **D(0,95): 14,71 µm**



Größen	Durchgang (%)	Größen	Durchgang (%)	Größen	Durchgang (%)
1,000	6,95	20,000	99,55	90,000	100,00
5,000	50,43	40,000	100,00	125,000	100,00
8,000	73,46	45,000	100,00	200,000	100,00
10,000	83,09	63,000	100,00	500,000	100,00

Kommentar: REINDICHTE : 2,49 BLAINE WERT : 5618

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Mastersizer 2000 Version 5.10G
S/N: MAL100312

Dateiname: Probenversand - Lager
Messdatensatz-Nr.: 45
09 Feb 2012 14:14:20

Figure C5: Information sheet Microsit M20