Research Programme of the Research Fund for Coal and Steel
Steel RTD

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Research Programme of the Research Fund for Coal and Steel

Six-monthly Report

Technical Report No: 4

Period of Reference: 01/01/2009 – 30/06/2009

Technical Group: TSG8

JoinTec
-
Innovative and competitive new joining technology for steel pipes using adhesive bonding

Contract Number: RFSR-CT-2007-00035

Contractors:
Universitaet Paderborn “UPB”
Salzgitter Mannesmann Forschung GmbH “SZMF”
GDF Suez “GDF”
Sika Danmark AS “SIKADK”
Centro Sviluppo Materiali SPA “CSM”
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Commencement Date: 01/07/2007

Completion Date: 30/06/2010

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European Commission
RFCS Programme
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I. SIX-MONTHLY PROJECT OVERVIEW

CATEGORY OF RESEARCH	Steel
TECHNICAL GROUP:	TGS8
REFERENCE PERIOD:	01/01/2008 – 30/06/2008
CONTRACT N°:	RFSR-CT-2007-00035
PROJECT N°:	RFSR-CR-07-035
TITLE:	JoinTec
CONTRACTOR(S):	- Universitaet Paderborn "UPB" - Salzgitter Mannesmann Forschung GmbH "SZMF" - Gaz de France SA "GDF" - Sika Danmark AS "SIKADK" - Centro Sviluppo Materiali SPA "CSM" - Salzgitter Mannesmann Line Pipe GmbH "SMLP" - Arbeitsgemeinschaft fuer Waerme und Heizkraftwirtschaft e.V. - AGFW- "AGFWEV"
COMMENCEMENT DATE:	01/07/2007
COMPLETION DATE:	30/06/2010
NEW COMPLETION DATE:	n/a

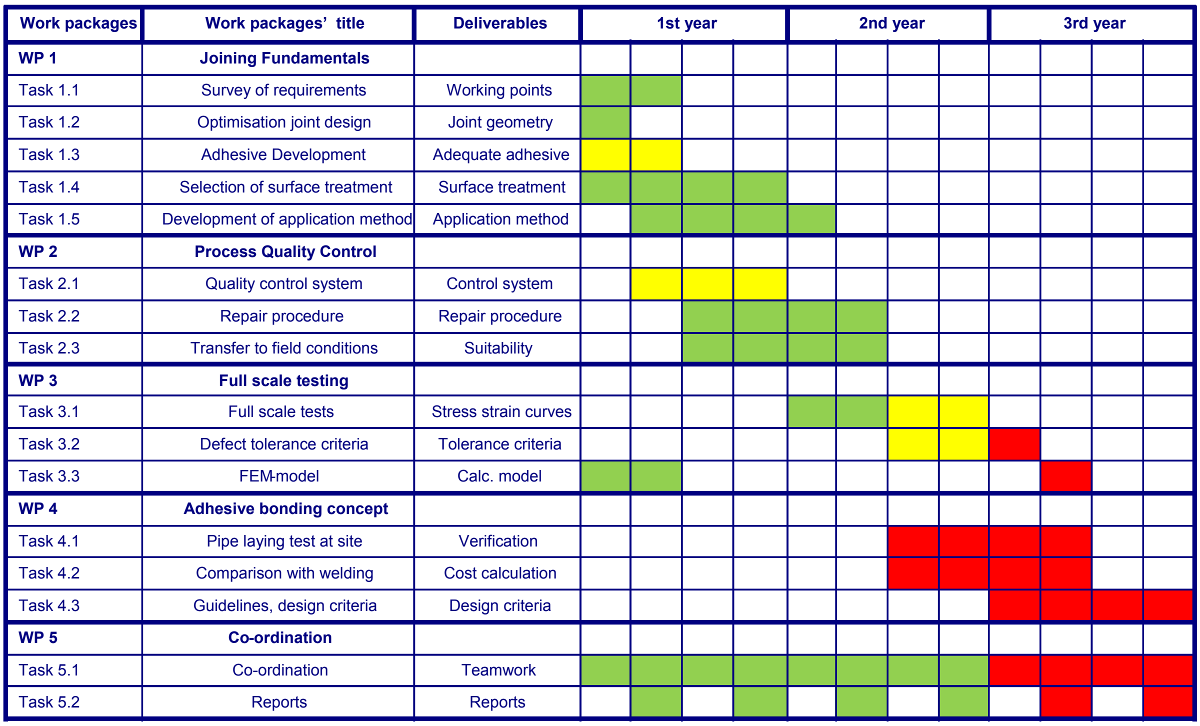
WORK UNDERTAKEN:	- Development of new adhesives - Application machine was chosen for adhesive application for full scale and laying tests - Joint geometry optimised using FE-method including experimental verification - 2C-primer tested for surface treatment on construction sites - Tests concerning manufacturing defects finalised - Additionally tests with alternative sleeve material performed - Climate tests on adhesively bonded pipes - Climate tests on the adhesive bulk - Joining concept scaled to full scale pipes - Full scale internal pressure tests on OD = 168.3 mm pipes - Qualification of proposed ultrasound techniques for pipe bonding
MAIN RESULTS:	- Two adhesive prototypes - Application method for full-scale and pipe laying tests - Knowledge about weak points of joining concept under concerns of ageing - Mechanical properties of adhesive under ageing influences - Test setup for fatigue tests on small scale pipe specimens; preliminary results of fatigue tests - Knowledge about curing of adhesively bonded pipes at room temperature - Test setup for accelerated curing of adhesively bonded pipes - Experiences in bonding full-scale pipes - Knowledge about behaviour of full scale pipes (OD = 168.3 mm) under internal pressure - Elaboration of modifications of pipe geometry resulting from experiences of full scale tests

FUTURE WORK TO BE UNDERTAKEN:	- Elaboration of test programme for / start of pipe laying tests - Tests on OD 168.3 mm pipes have to be continued and finalised - OD = 508 mm pipes have to be bonded / full scale tests have to be started - Preparation of guidelines for full scale pipe bonding - Cost comparison between welded and adhesively bonded pipes - Optimisation of resistance of bonded pipes against corrosion - Fatigue tests of small scale pipe specimens have to be continued
ON SCHEDULE (*YES /NO)*:	No
PROBLEMS ENCOUNTERED:	Amendment no. 1 to the contract is not ratified by all project partners. Therefore, pipe laying tests could not be started, yet.
CORRECTION – ACTIONS	Elongation of the project requested.
BUDGET INFORMATION PER PARTNER:	- Universitaet Paderborn “UPB” Budget: **490.548 €** - Salzgitter Mannesmann Forschung GmbH “SZMF” Budget: **425.693 €** - Gaz de France SA “GDF” Budget: **9.211 €** - Sika Danmark AS “SIKADK” Budget: **128.975 €** - Centro Sviluppo Materiali SPA “CSM” Budget: **280.000 €** - Salzgitter Mannesmann Line Pipe GmbH ”SMLP” Budget: **92.650 €** - Arbeitsgemeinschaft fuer Waerme und Heizkraftwirtschaft e.V. - AGFW- “AGFWEV" Budget: **9.720 €**
TOTAL BUDGET (EURO) :	**1.548.635**
PUBLICATIONS – PATENTS :	n/a

II. TABLE OF CONTENTS

1. PROGRAMME BAR CHART

Figure 1 shows the progress of the JoinTec project at the end of the second reporting period.



Work packages	Work packages' title	Deliverables	1st year				2nd year				3rd year			
WP 1	**Joining Fundamentals**													
Task 1.1	Survey of requirements	Working points	🟩	🟩										
Task 1.2	Optimisation joint design	Joint geometry	🟩											
Task 1.3	Adhesive Development	Adequate adhesive	🟨	🟨										
Task 1.4	Selection of surface treatment	Surface treatment	🟩	🟩	🟩	🟩								
Task 1.5	Development of application method	Application method		🟩	🟩	🟩	🟩							
WP 2	**Process Quality Control**													
Task 2.1	Quality control system	Control system		🟨	🟨	🟨								
Task 2.2	Repair procedure	Repair procedure			🟩	🟩	🟩	🟩						
Task 2.3	Transfer to field conditions	Suitability			🟩	🟩	🟩	🟩						
WP 3	**Full scale testing**													
Task 3.1	Full scale tests	Stress strain curves					🟩	🟩	🟨	🟨				
Task 3.2	Defect tolerance criteria	Tolerance criteria							🟨	🟨	🟥			
Task 3.3	FEM-model	Calc. model	🟩	🟩								🟥		
WP 4	**Adhesive bonding concept**													
Task 4.1	Pipe laying test at site	Verification							🟥	🟥	🟥	🟥		
Task 4.2	Comparison with welding	Cost calculation							🟥	🟥	🟥	🟥		
Task 4.3	Guidelines, design criteria	Design criteria									🟥	🟥	🟥	🟥
WP 5	**Co-ordination**													
Task 5.1	Co-ordination	Teamwork	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥
Task 5.2	Reports	Reports		🟩		🟩		🟩		🟩		🟥		🟥

Figure 1: programme bar chart

2. ABSTRACT

The fourth project period dealt with the items described in the following:

Prototype adhesives have been developed which are offering high adhesive strength on steel adherents and improved mechanical properties. Tests will be performed to check if the improved mechanical properties of the adhesive will also lead to improved mechanical strength of adhesively bonded pipes.

Using the FE-method, the stress distribution in the adhesive bondline was analysed qualitatively. Basing on the findings made by simulations, different geometry modifications were made to lower the stresses in the critical areas of the adhesive bond. Three of these modifications seemed to be most promising and were identified to be verified in tests with small scale pipe specimens. All of the three modifications lead to increased mechanical properties of the bonds. One of these geometries seems to be most promising under the aspects of stress distribution and will be used for further modifications.

As said, coatings on epoxy basis have positive effects on the strength of adhesively bonded pipes. As the pipes for full scale testing and laying tests are uncoated, a 2C-epoxy primer was chosen which can be applied by brushing. Tests were performed to proof the positive effects of this coating on the strength of adhesively bonded pipes, too. It turned out, that the cohesive strength of the 2C-epoxy primer was to weak. Instead of a failure of the adhesive, the primer failed leading to reduced bond strength, which was even lower than the strength reached in using uncoated pipes. This seems to be related to the fact that the 2C-epoxy primer is could curing, whereas all other testing primers were cured at 180°C, what indicates a more enhanced strength. As there are no positive effects in using a 2C-epoxy primer expectable, it was decided to perform the full scale and the laying tests with uncoated pipes.

Tests with an alternative sleeve material were performed with unpromising results. Steel sleeves will be used as auxiliary joint furthermore.

Tests in analysing processing defects were completed. The most critical failures could be identified and countermeasures could be derived from these findings.

Climate tests were made according to VW-P1200 and VDA621-415 standards. These tests had major negative effects on the strength of the bonded pipes. In a next step, the weaknesses of the joints will be annihilated.

Preliminary fatigue tests on small scale pipes have been performed.

Elaborated joining concept was transformed to be used on medium sized full scale pipes.

Full scale tests on OD168.3xWT7.1 mm were performed. Aim of these tests was to check the maximum reachable pressure in the pipes before rupture. Maximum pressure of 119 bar could be reached. Several problems and findings resulted while bonding the pipes, which lead to important experiences concerning the preparation of instructions for pipe bonding. In addition, the need of further geometry modifications became obvious and several modifications have been evaluated.

The proposed non destructive testing methods were qualified for the use in pipe bonding.

3. INTRODUCTION

Joining techniques such as welding, brazing, riveting and screwing are used by industry all over the world on a daily basis. As a result of the very successful developments in recent years a further method of joining is becoming more and more important and is already a key technology in many areas: adhesive bonding.

The main innovative value of this research work is the introduction of the pace developments in adhesive bonding technology of recent years into the steel pipe industry by means of an interdisciplinary European team work between leading companies and research facilities from the steel and the adhesive industry. The joining concept will be based on the present pipeline requirements including operation and maintenance processes.

Main objective is the development of an efficient, integrated and easy-to-use joining technique for adhesive bonding of steel pipes. In addition, guidelines, design calculation methods and non-destructive testing methods including a repair concept for adhesively bonded steel pipes have to be developed. To guarantee the transferability of the elaborated bonding concept, pipe laying tests, using the developed technology will be performed including the appliance of a non-destructive, to be developed testing method as an instrument for quality control. In addition, cost calculations and cost comparisons to conventional joining technologies will be performed to prove the economical benefit of adhesive bonding for pipe-joining.

The report at hand treats with the research work done in the second six-month period of the JoinTec project. It consists of the research work of the following working packages:

Work package 1:	Joining Fundamentals
Work package 2:	Process Quality Control
Work package 3:	Full scale testing
Work package 5:	Co-ordination

4. WORK PACKAGE 1: JOINING FUNDAMENTALS

4.2. Task 1.2: Optimisation of joint design

As reported before, the joint geometry for adhesively bonded steel pipes consists of two steel pipes, facing to each other. The abutting faces are sealed with a sealing material preventing an adhesive leakage into the pipe and, on the other hand, preventing the conducted medium in influencing the adhesive layer. The steel sleeve, which acts as an auxiliary joining is positioned centred on the abutting faces of the pipes and aligned using steel wedges, which are driven defined between the steel sleeve and the pipes. The generated gap is used as bondline, as the adhesive will be injected into this gap. For preventing an adhesive leakage, the gap is sealed using heat shrinking material (Figure 2).

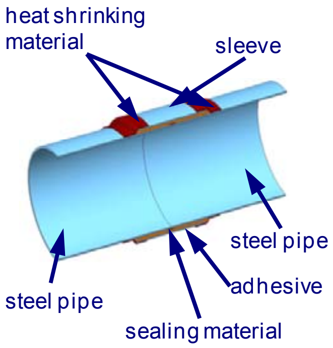


Figure 2: Principle for pipe joining

4.1.1 Optimisation of stress distribution in the adhesive layer

Tensile tests show that failure of bonded pipes proceeds in two stages: first, the adhesive is stressed by direct stresses until a first maximum of tensile force is reached. After that, shear stresses appear mainly, leading to a second, global maximum tensile force. To optimise the behaviour of adhesively bonded pipes under tension loads, simulations using the FE-method were started to explain the proceeding of the failure of the pipes and to get indications, how the joint geometry can be optimised to resist even higher tensile forces. A FE-model was set-up of the standard joint geometry using the technical data of the pipes and the adhesive as input. As a material law, a linear elastic behaviour was chosen. Tensile forces of 35 kN were applied in axial direction of the pipes. The stress distribution was analysed and plotted at the bottom side of the pipe bond, the middle of the adhesive layer and at the upper side of the adhesive layer (Figure 3).

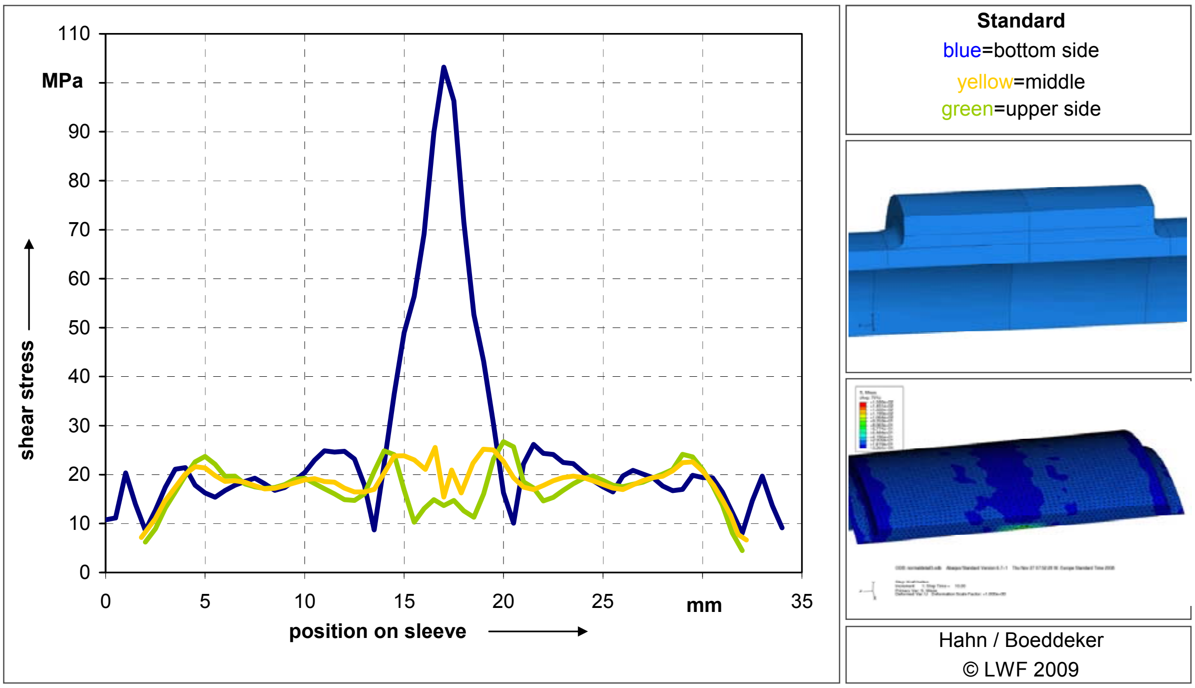


Figure 3: axial stress distribution of adhesively bonded steel pipes under tensile loads using standard pipe geometry

Due to the implemented material law, stresses were not lowered through relaxation. Though, the results do not represent the real stresses in the adhesive layer, but the plotted stress distribution shows the weaknesses of the pipe joint. Using standard joint geometry, a stress peak appears at the abutting faces of the pipes at the bottom side of adhesive layer. As such high stresses can not be resisted by the adhesive, it is evident that failure of the joint appears at this position first. To proof this thesis, a pipe specimen was loaded with 35 kN. Then, the test was aborted and a microsection of the joint was prepared (Figure 4).

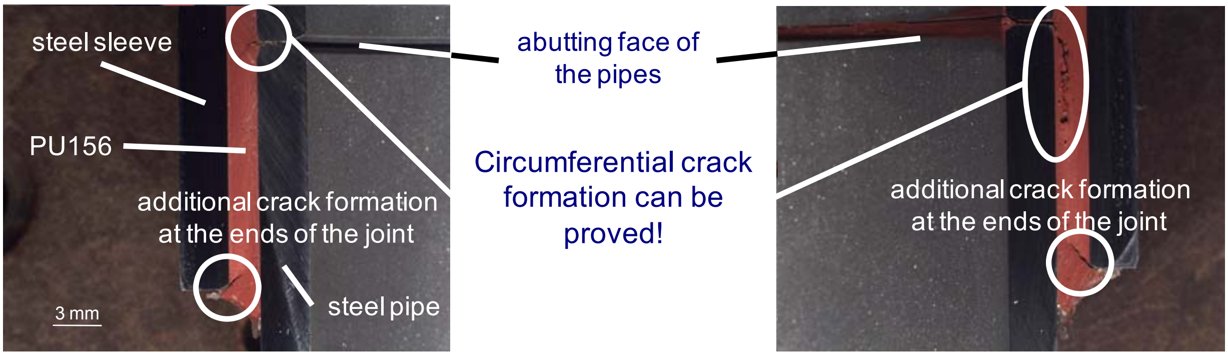


Figure 4: Crack propagation on adhesively bonded pipes

It can be seen that cracks appear at the abutting edges as assumed after analysing the FE results. In addition, cracks appear at the end of the sleeves. Basing on these findings, the joint geometry was modified. Below, you will find schematic drawings of the proposed geometry modifications showing the main features of the modifications (Figure 5).

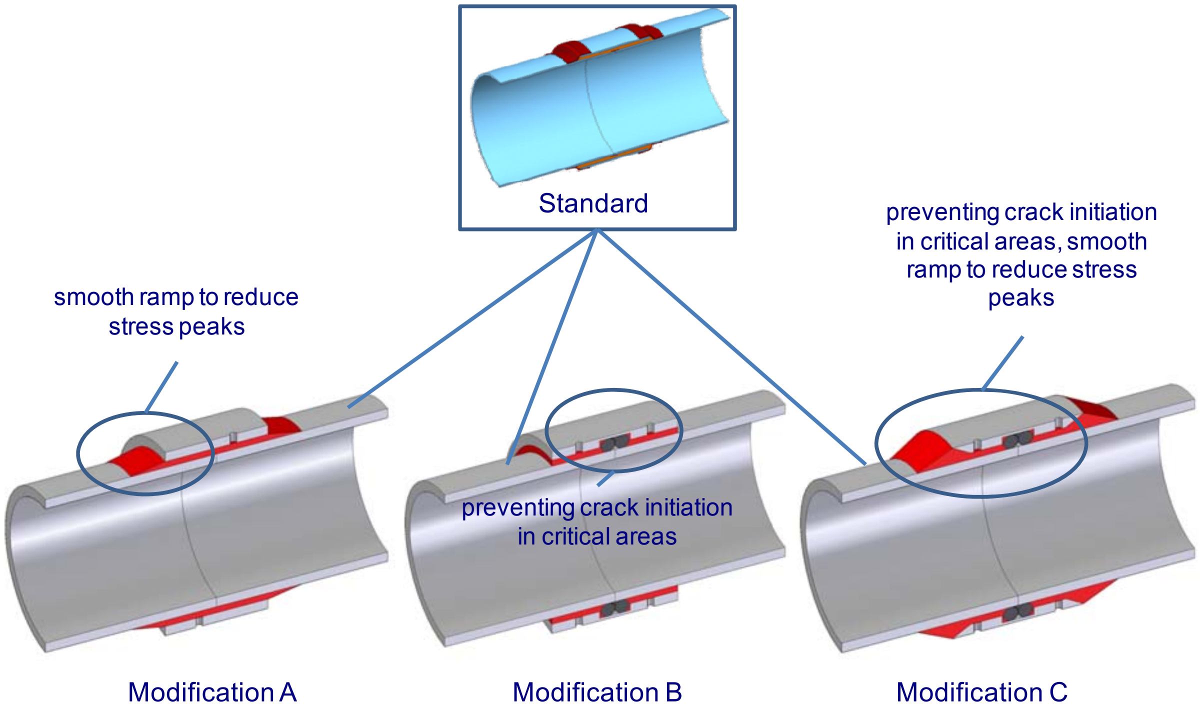


Figure 5: Modification of joint geometry to enhance the tensile strength of the adhesively bonded pipe specimens

In developing these modifications, the focus was on keeping the assembly of the pipe specimens as simple as before. However, additional mouldings had to be designed and build to realise the geometry modifications of the adhesive layer.

Modification A consists of a smooth ramp of the adhesive layer outside the sleeve. This modification should reduce stress peaks at the end of the overlapping of the sleeve. In modification B, o-rings were used as spacers directly at the abutting faces of the pipes. This should prevent direct stresses on the adhesive layer appearing at this location. Unlike the standard geometry, geometry modification B offers an adhesive layer which is only loaded with shear loads. The reduced overlapping, due to the sealing rings, is compensated by elongating the sleeve. As a third model, modification C was developed. It consists of the main features of modification A and B. The adhesive layer was designed as a fillet with an internal taper and o-rings at the abutting faces, comparable to modification B.

Using these modifications, FE-simulations were started to analyse whether these modifications have a positive influence on the stress distribution in the adhesive layer, or not.

Figure 6 shows the stress distribution using joint geometry modification A.

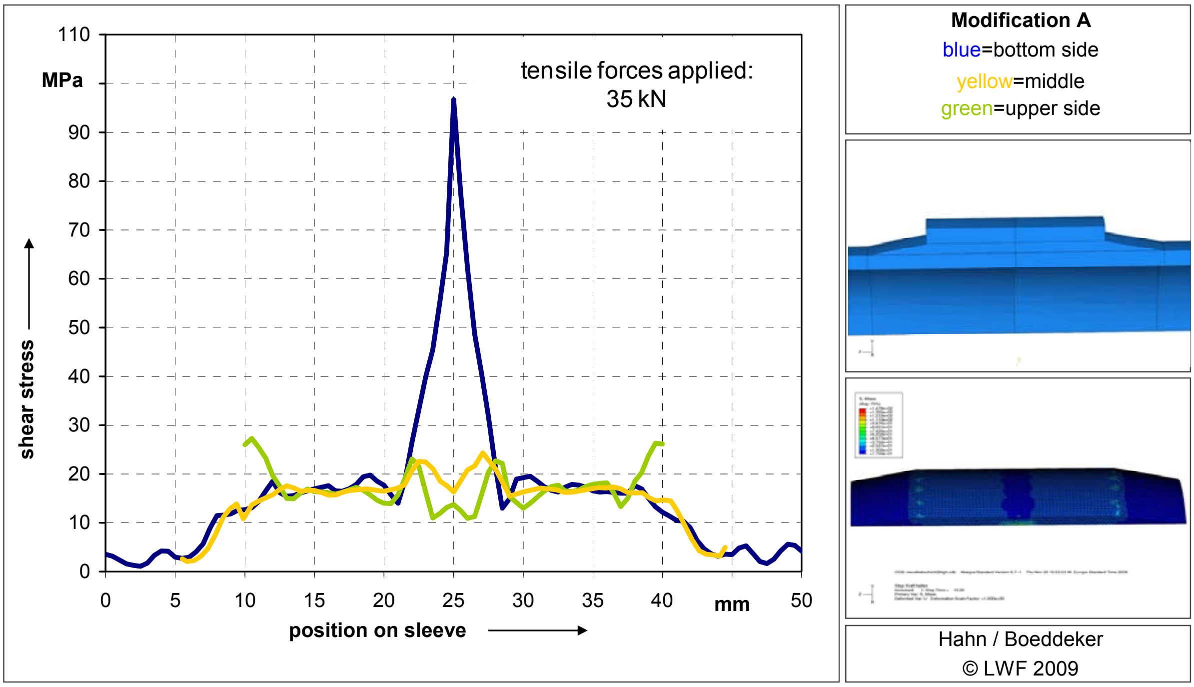


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Figure 6: axial stress distribution of adhesively bonded steel pipes under tensile loads using geometry modification A

It can be seen that the stress distribution propagates more smoothly as it did in using the standard geometry. The stress peak at the abutting faces of the pipe is not affected by this modification. In addition, stress peaks appear on the upper side of the adhesive layer on the edge of the sleeve.

In Figure 7 the stress distribution in the pipe joint in using geometry modification B is displayed. It is obvious, that the stress peak at the abutting faces of the pipes could be avoided. Thus, the level of shear stresses increased slightly.

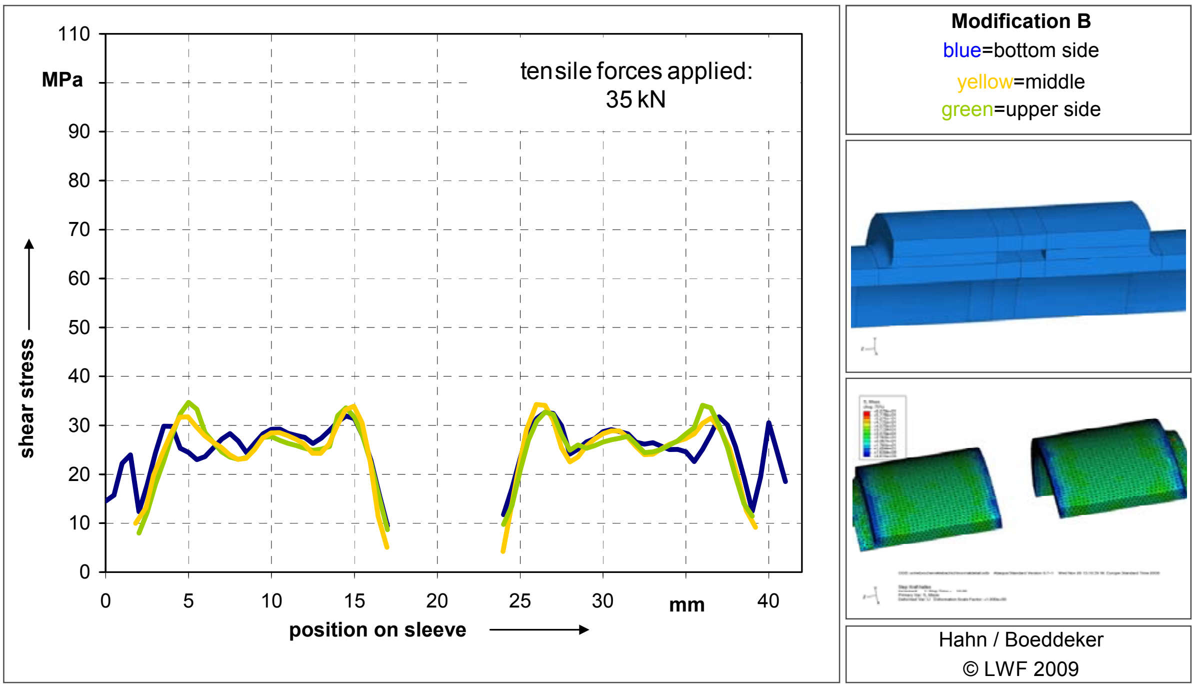

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Figure 7: axial stress distribution of adhesively bonded steel pipes under tensile loads using geometry modification B

The stress distribution in the adhesive layer using joint geometry C can be seen in Figure 8.

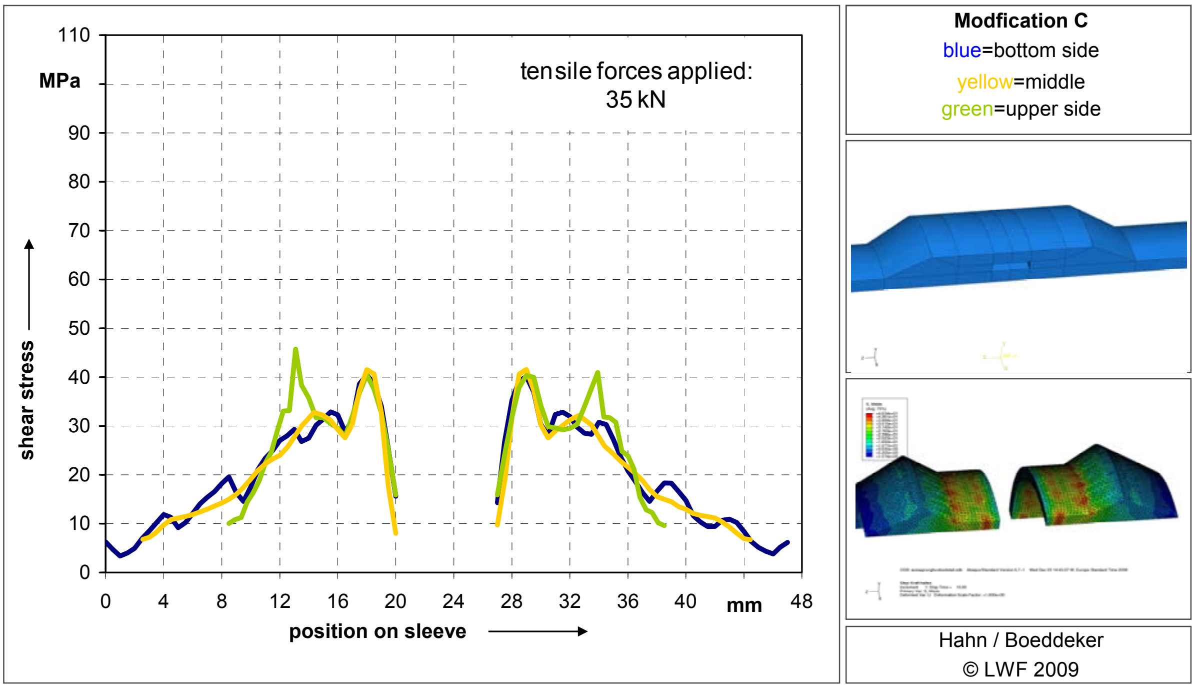


Figure 8: axial stress distribution of adhesively bonded steel pipes under tensile loads using geometry modification C

In using joint geometry C, the stress peaks at the abutting faces of the pipes can be reduced as well. Results show that the shear stresses increase smoothly beginning at the edges and reaching their maximum in the middle of the specimen. The stress distribution on the upper side of the adhesive layer has one major stress peak at the edge of sleeve. Due to the taper, the adhesive gets an additional direct stress component.

The modified joint geometries not only were analysed in using the FE-method, but also in a tensile test. The consolidated results of these tensile tests can be seen in Figure 9.

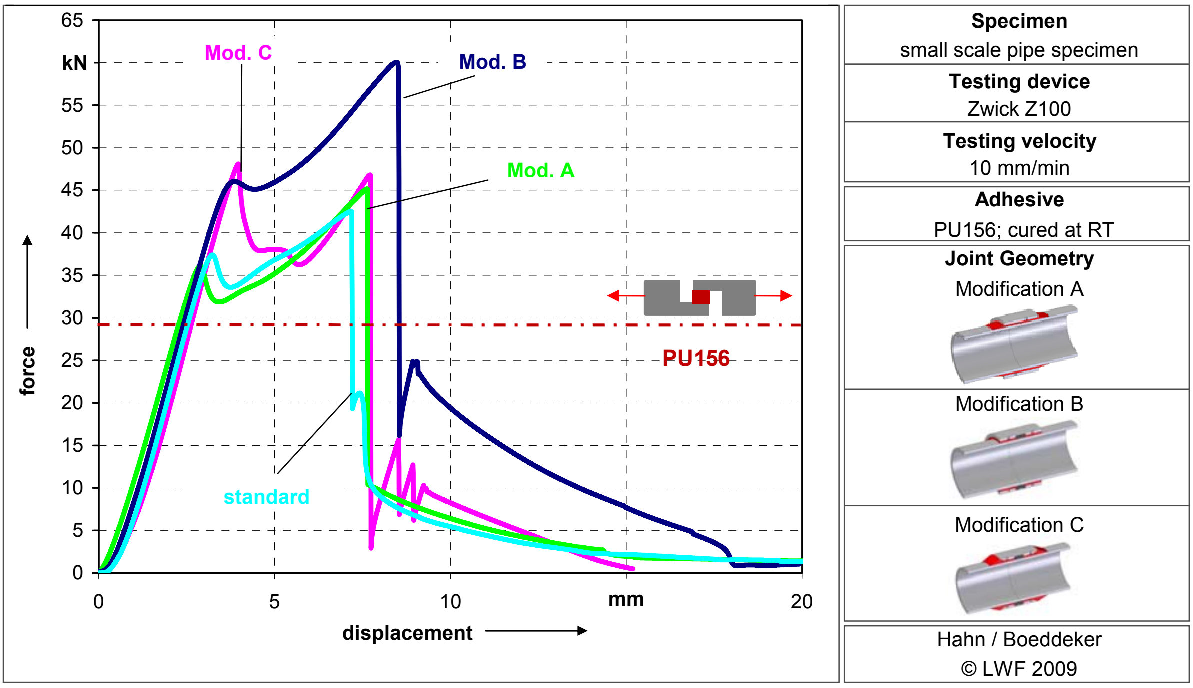


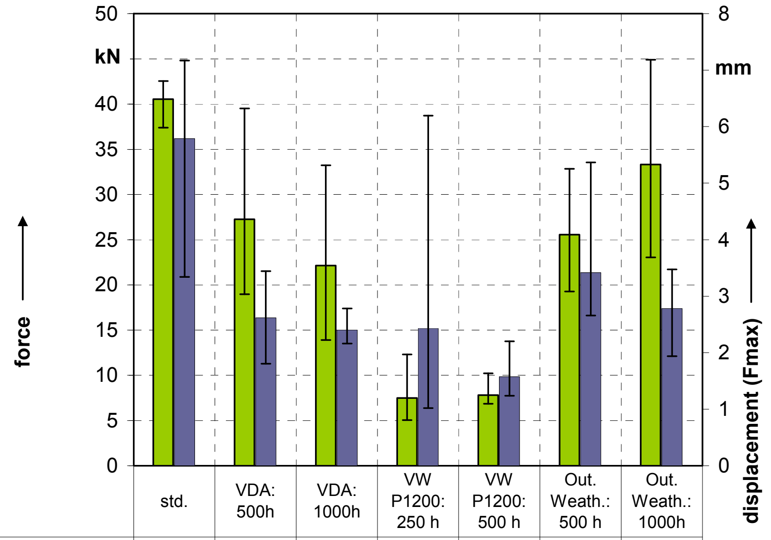
Figure 9: Force-displacement-curves of pipe specimens with standard joint geometry and geometry modifications A, B & C under tensile loads

The force-displacement-curves show that by using joint geometry A, maximum shear forces could be increased slightly in comparison with the standard joint geometry. The first point of discontinuity in the force-displacement-curve, which indicates an initial failure of the adhesive bond, could not be increased by using this modification. Using joint geometry B leads to significant higher tensile forces. Maximum forces of about 60 kN can be reached. The initial failure by using this joint geometry could even be increased of about 25 %. Modification C leads to increased mechanical properties as well. An initial strength of about 45 kN can be reached. After this first maximum, the strength of the specimen decreases to a minimum of about 35 kN and increases afterwards to values of 45 kN. While reaching the first maximum, the adhesive is stressed in a combination of direct stresses and shear stresses in the region of the taper, which is a disadvantageous load case for the adhesive, leading to an initial failure at this point. After that, the adhesive is mainly loaded with shear-stresses what results in the second force maximum. This maximum is not as high as in using geometry B, what is related to the reduced bond area to transmit shear forces due to the taper. Due to manufacturing reasons and due to the fact that modification B offers additional safety after reaching the initial failure, modification B was pointed out to be further modified.

In addition to the bond strength, Figure 9 shows the expected strength of the bond, which might be reached, if the tensile strength of the adhesive, which was determined in using the thick tensile specimen, serves as a basis for calculations. Using geometry modification B, nearly 100 % increase of the tensile strength of the adhesive could be achieved. This seems to be related to the much better stress distribution in a tubular shaped adhesive bond line which inhibits stress related edge effects, but has to be clarified by further investigations.

4.1.2 Optimisation of joint design in concerns of corrosion protection

As pipelines are used in the field, they are exposed to various climate influences during they service life. These climate influences will affect the strength of the adhesives and the bond. As pipes are supposed to stay in service for more than 30 years, this long term weathering has to be emulated in laboratory scale. Therefore, tests were performed to simulate this climate influences on the strength of the pipes. The tests performed are the P VW 1200 test according to a test standard of Volkswagen AG and the VDA 621-415 which is a test standard of the automotive industry as well. The effect of these tests shall be worse than the effects, climate has on earth-laid pipelines due to the wide range of temperatures and, especially in using VDA 621-415, the use of NaCl as a corrosive medium, which affects the pipes additionally. These tests will help to identify the weaknesses of adhesively bonded steel pipes under a climate influence and will help to develop countermeasures. Results of the climate tests can be seen in Figure 10.



	std.	VDA: 500h	VDA: 1000h	VW P1200: 250 h	VW P1200: 500 h	Out. Weath.: 500 h	Out. Weath.: 1000h
🟩 force [kN]	40,56	27,24	22,13	7,47	7,81	25,56	33,31
+	1,98	12,28	11,09	4,84	2,40	7,28	11,59
-	3,17	8,27	8,25	2,43	0,96	6,29	10,26
🟪 displ. (Fmax) [mm]	5,79	2,62	2,40	2,43	1,58	3,41	2,78

Specimen
small scale pipe specimen

Testing device
Zwick Z100

Testing velocity
1 mm/min

Adhesive
PU156

Curing
RT; 10 d

Ageing
see diagram

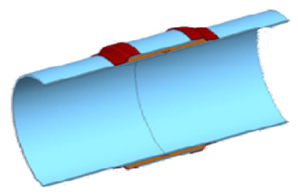


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Figure 10: bond strength of climate aged small scale pipe specimens

It can be seen that VDA 621-415 has significant negative effects on the bond strength. Forces decreased to an average value of 27.24 kN, accompanied with a wide variance of the results. Ageing for 1000 h leads to even worse results. Strength decreased to 22.13 kN in average. Test VW P1200 has an even worse effect on the strength of adhesively bonded pipes. Here, after 250 h and 500 h of ageing, only 7.50 kN could be reached. Having a look at the appearances of fracture explains the problems occurred (Figure 11).

VDA 621-415: 1000 h

VW P1200: 500 h

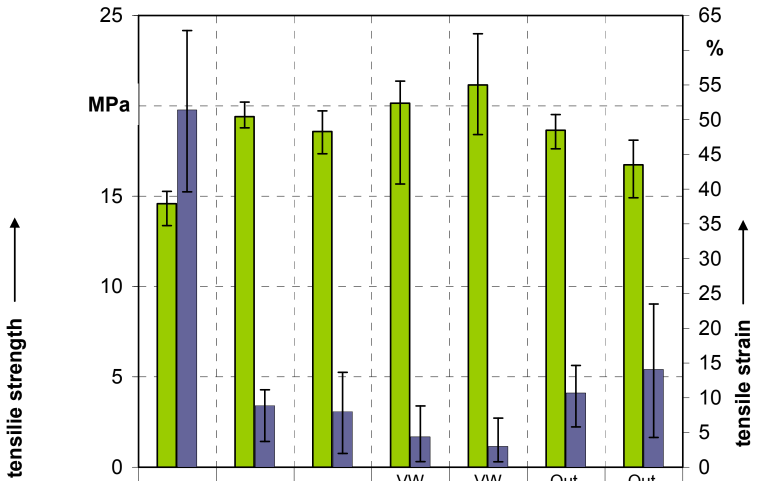
Outdoor weathering: 1000 h

Figure 11: Appearances of fracture of small scale pipe specimens aged under VDA 621-415, VW P1200 and outdoor-weathering

Especially the VDA 621-415 affects the pipes significantly. The pipes are massively corroded. The corrosion was able to creep under the shrinking material so that the adhesive could be affected as well. Similar effects can be detected in having a look at the picture of the VW P1200 aged small scale pipe specimen. The pipes were corroded as well and the shrinking material was completely peeled off from the pipes. The colour of the adhesive in the appearance of fracture shows a dark discolouring what indicates an influence of humidity on the adhesive bulk. In analysing the appearance of fracture of the outdoor weathered pipes, it can be seen that humidity was able to affect the pipes from the inside, so that the interface between the steel surface and the adhesive was impaired.

Basing on these results, the pipes will be modified: In a first step, the pipes and sleeves for further corrosion tests will be coated. This will prevent corrosion of the steel pipes and creeping of humidity beneath the shrinking material. In previous tests, the positive effect of coatings on the strength of pipe bonds was already shown. In addition, special seals for sealing the butt-joint will be developed to hinder humidity in getting in contact with the adhesive from the inside of the pipes.

Climate influences on bulk specimens were investigated as well using the testing methods mentioned before. The results can be seen in Figure 12.



	std.	VDA: 500h	VDA: 1000h	VW P1200: 250 h	VW P1200: 500 h	Out. Weath.: 500 h	Out. Weath.: 1000h
🟩 tensile strength [MP]	14,59	19,41	18,58	20,14	21,15	18,65	16,74
+	0,67	0,81	1,15	1,23	2,84	0,87	1,36
-	1,21	0,62	1,23	4,47	2,74	1,03	1,83
🟦 tensile strain [%]	51,41	8,87	8,01	4,37	2,97	10,67	14,08

Specimen
tensile specimen
Testing device
Zwick Z100
Testing velocity
1 mm/min
Adhesive
PU156
Curing
RT; 10 d
Ageing
see diagram

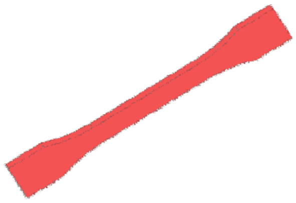


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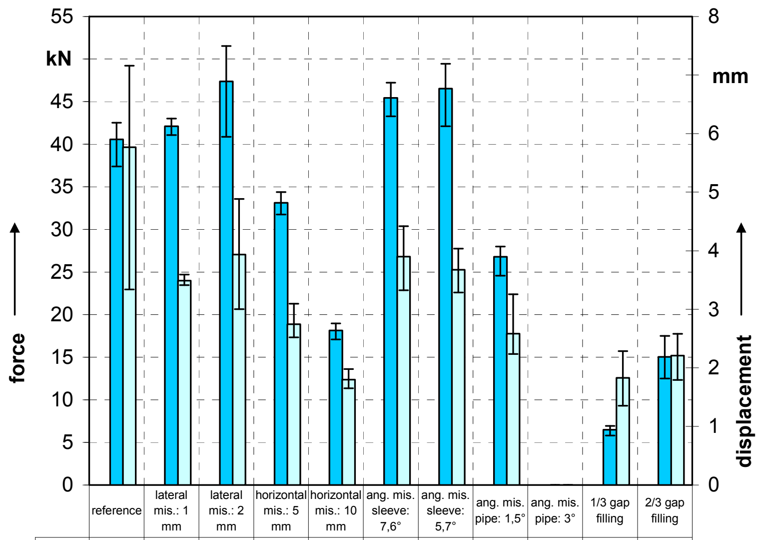
Figure 12: Climate influence on the strength and elongation of PU156 adhesive bulk specimens

It can be seen that the strength of the adhesives increases by aging the specimens. This is related to an additional curing of the adhesives at higher temperatures in VDA 624-415 and VW P1200. But it can be seen as well, that the adhesive gets a more brittle behaviour. Stress peaks will not be lowered through relaxation. This explains why the aged pipe specimens achieved significantly lower strength although the strength of the adhesive could be enhanced. Another problem, not related to the adhesive bulk is the adhesion on the steel pipes, which is disturbed by the affected interface caused by corrosion.

4.1.3 Influence of processing defects on adhesively bonded pipes

The tests investigating the influence of processing defects on the strength of adhesively bonded pipes on construction sites were finalised. The results which have not been presented until now are the angular misalignment of the sleeves of about 5.7°, the angular misalignment of the pipes of 3° and an incomplete filling of the adhesive gap of about two thirds and one third (Figure 13). An angular misalignment of the pipes of 3° could not be realised due to an adhesive leakage into the pipe.



	reference	lateral mis.: 1 mm	lateral mis.: 2 mm	horizontal mis.: 5 mm	horizontal mis.: 10 mm	ang. mis. sleeve: 7,6°	ang. mis. sleeve: 5,7°	ang. mis. pipe: 1,5°	ang. mis. pipe: 3°	1/3 gap filling	2/3 gap filling
■ F max	40,56	42,13	47,38	33,11	18,14	45,44	46,54	26,79	0,00	6,48	15,04
+	1,98	0,90	4,16	1,26	0,84	1,80	2,90	1,21	0,00	0,45	2,45
-	3,17	1,05	6,49	1,35	1,06	2,17	4,43	2,20	0,00	0,69	2,55
□ s max	5,77	3,49	3,94	2,75	1,80	3,90	3,67	2,58	0,00	1,83	2,21

Specimen
small scale pipe specimen

Testing device
Zwick Z100

Testing velocity
10 mm/min

Adhesive
PU156; cured at RT

Manufacturing failure
see diagram

Overlapping
30 mm

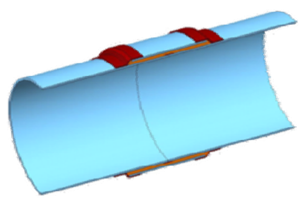


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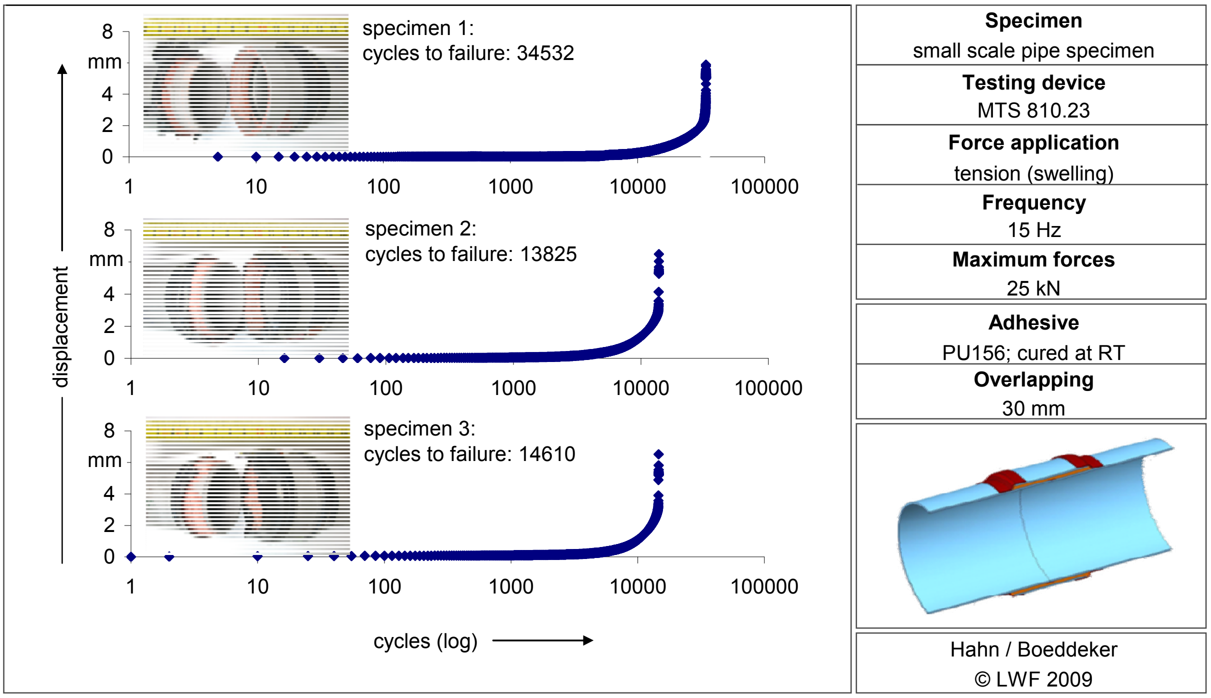
Figure 13: Influence of processing defects on the strength of adhesively bonded pipes

It can be stated that not every processing defect has negative effects on the strength of adhesively bonded pipes. The most crucial mistakes are the horizontal misalignment of the pipes, as this results directly in a reduced bond strength, the angular misalignment of the pipes, as the angle of load application changed, and the incomplete filling of the bondline. These mistakes can be avoided easily. Horizontal misalignment of the sleeves can be avoided by marking the correct position on the pipes. The correct position of the sleeves has to be affirmed by workers in a protocol which has to be made for quality assurance purposes. The angular misalignment of the pipes is not relevant for field bonding of the pipes as they are fixed by an centring device which should always align the pipes correctly. In addition the position of the pipes can be determined by using a water level. The complete filling of the gap can be checked easily in having a look at the adhesive outlet on the upper side of the pipes. If the adhesive leaks out of the upper boreholes of the sleeves, the gap can be assumed as completely filled.

4.1.4 Fatigue tests on adhesively bonded pipes

Using the standard pipe geometry, preliminary tests were performed to get indications about the fatigue strength of the bonded pipes (Figure 14). Using a swelling test setup with maximum tensile forces up to 25 kN leads to maximum cycles between 13,825 and 34,532. Due to high dynamic forces, the rod ends were worn after these three tests. The tests have to be postponed until more suitable rod ends have been chosen. After that, tests will be continued and the area of the low cycle fatigue up to 100,000 cycles, which is most interesting in concerns of pipe service, will be investigated.



Specimen
small scale pipe specimen
Testing device
MTS 810.23
Force application
tension (swelling)
Frequency
15 Hz
Maximum forces
25 kN
Adhesive
PU156; cured at RT
Overlapping
30 mm

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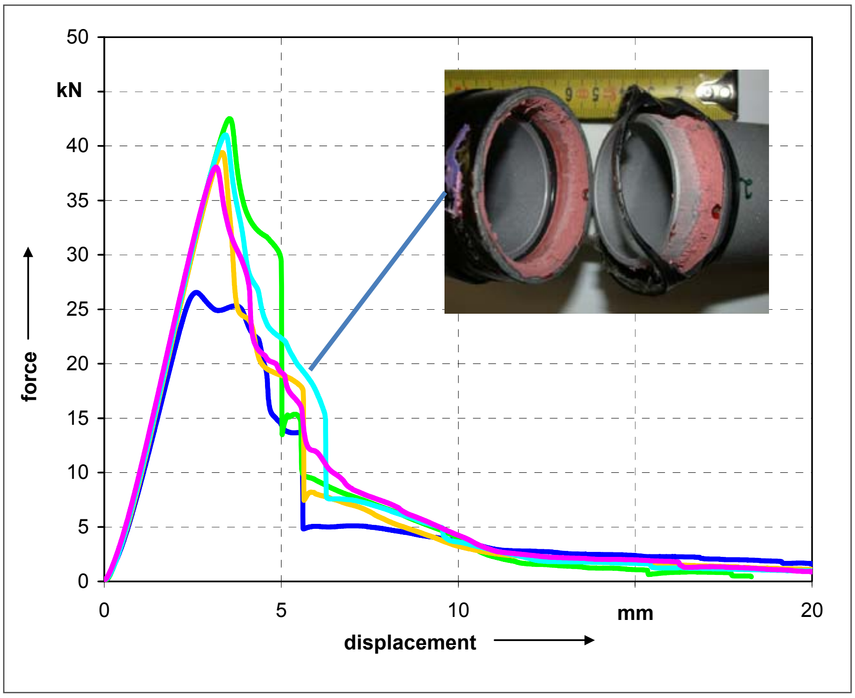
Figure 14: Preliminary dynamic strength test

4.1.5 Use of different sleeve materials

The use of different sleeve materials was discussed in the project team. The results in using a sleeve made of HD-PE were already reported. These tests were not promising due to a missing adhesion of the adhesive on the sleeve material. In addition, problems arose in using the specially developed sealing integrated joint geometry. The integrated sealing slipped from its position and impeded the complete injection of the adhesive into the bond line. It was decided to make tests using glass fibre reinforced plastics as sleeve material. The material was delivered as pipes from which the geometry needed was machined. Figure 15 shows the results of tensile tests made with adhesively bonded pipes with GFRP sleeves.



Specimen
small scale pipe specimen

Testing device
Zwick Z100

Testing velocity
10 mm/min

Adhesive
PU156

Curing
RT; 10 d

Sleeve
glass fibre reinforced plastic

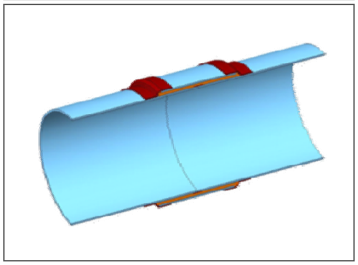


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Figure 15: force-displacement-curve of adhesively bonded pipe specimens with GFRP sleeves

It can be seen that the stiffness of all specimens is on the same level. The failure can be characterised as brittle with nearly no deformation. The appearance of fracture can be described as a cohesive, respectively interface near cohesive failure. Forces of about 37.5 kN can be reached. In comparison with standard pipe specimens with steel sleeves, the GFRP sleeves do not offer advantages concerning strength. In addition it has to be taken in mind that all forces resulting from pipe laying and from pipe service have to be distributed by the sleeves. This means that the pipe connection or respectively the auxiliary joint will always be the weak point of the connection. For this reason, the project team decided to continue to use steel as sleeve material.

4.2 Task 1.3: Adhesive Development

Previous screening and analyses showed that PU156 had promising results regarding the adhesion of steel pipes. In order to present a new adhesive at the end of this project – a "two-step" behind analysis of a new formulation is made in order to have results showing what to modify in the new adhesive.
The PU156 is a commercial product of Sika Danmark A/S, sold for applications where strength is an important issue, and one of the applications implies a steel component which might have predetermined some of the additives e.g. the wetting agent. The base part of a new adhesive should show at least the same strength and adhesion to the steel but in this screening period. To continue with the new formulation higher lap-shear strengths (adhesion strength) and higher tensile strengths will be the initial parameter to determine "fail or success"

Ten different formulations (PU201 - PU210) where made and mixed for making dog-bones and lap-shear specimens using sandblasted steel where provided by UPB.
Dog-bones for tensile tests were prepared by curing 10 days at room temperature (23 °C). The dog-bones were tested according to ISO-527-2 at 2 mm/min using an Instron 5567. The

lap-shear specimens where prepared and left to cure at 23 °C for 10 days. The analysis was made using ISO 4587.

In table 1 the results from the tensile tests performed at room temperature are listed.

Table 1: Modified versions of the PU-156

Modification	PU-201	PU-202	PU-203	PU-204	PU-205	PU-206	PU-207	PU-208	PU-209	PU-210	PU-156
TSx [MPa]	26,71	30,34	27,5	15,2	36,61	34,31	N.A	N.A	N.A	N.A	18
%Elongb [%]	2,04	1,57	1,05	3	2,30	2,15	N.A	N.A	N.A	N.A	4
E-modulus [MPa]	2260	2430	2600	1510	2947	2705	N.A	N.A	N.A	N.A	2240
Lap-shear	20,23	25,45	23,17	8,02	31,40	30,80	2,01	4,15	3,56	3,23	14,1

As it can be seen from the table 1 - the strengths are significantly improved - but with lowered flexibility. The formulations PU-207 to PU-210 showed no adhesion to the metal specimens and the additives used in these formulations cannot be used. The tensile test was not performed on these samples.

However, samples PU-201 to PU-206, except PU-204, showed significant strength improvements compared to PU-156. PU-201 and PU-202 have approximately same viscosities as PU-156 and a curing time suitable for the gap-filling. The system PU-203 was very brittle and splintered when the tensile strength was achieved – the other specimens showed tough behaviours. Modification PU-205 and PU-206 showed the best performances regarding the strengths but an additive made them very high-viscous after 30 s. The very high viscosity is for sure not suitable for pumping and will act like a plug so that filling of the gap will be obstructed. This screening showed two possible candidates to be further examined. Samples have been shipped to UPB for further analyses. Further analyses are made at Sika Danmark meanwhile, regarding the topics discussed on last group meeting.

In Figure 16, lap-shear specimens are presented to show the adhesive failure from PU-201. PU-202 looks the same.

Figure 16: lap-shear specimens of PU-201 one side

Besides the adhesive development it was evaluated which adhesive application method can be used in processing the adhesive in the field. Considerations were made with two application methods.

2C-cartridge system:

Benefits of the 2C-cartridge system are the easy handling in the field due to its low weight. An energy support like pressurised air or electricity is not recommended.

Drawbacks are that filling of the cartridges is an issue without proper filling equipment. Problems may occur when adhesives with an unusual mixing ration have to be used as only standard cartridges are available. In addition, the use of manual dispenser guns results in slow filling.

Figure 17: 2C-cartridge system

2C-application machine:

The benefits in using an 2C-application machine are the continuous and exact mixing of the adhesive. In addition, all sizes of adhesive containers can be used. Small application machines are easy to transport. Disadvantages are the handling of the machine as it can not be operated by unqualified workers and energy supply is needed additionally.

Figure 18: 2C-application machine

At Sika Danmark A/S it was decided that the application machine would be the best method of application with this “minor” test since. Small equipment is present at Sika Danmark A/S which can be relatively easy moved.

Conclusion:

Work on the adhesive is still ongoing even though it was decided to continue using PU156. New solutions show better properties than the used one regarding strength and adhesion strengths. Samples have been shipped to UPB for further analyses. Further work on the adhesive formulation is necessary when results are obtained from the analyses before a new adhesive can substitute the PU156.

Application method was decided upon.

4.3 Task 1.4: Selection of economical and technological beneficial surface treatment

Surface pre-treatment is essential in achieving a high grade and durable adhesive bond. As already shown, surface pre-treatments on epoxy base, which are already in use in pipe production, have a beneficial influence on the strength of adhesively bonded pipes: The adhesion of the adhesive on the bonded pipes could be enhanced as well as the strength of the bond. In using epoxy-coatings, regardless which special coating from the pipe manufacturing process was used, the strength of adhesively bonded pipes could be enhanced by nearly 37 %. Due to these positive effects, the pipes to be bonded shall be coated in the pipe factory.

Alternatively it seems interesting to use 2C-epoxy primers which can be applied by brushing or spraying, as they offer the possibility of pipe coating even at construction sites under field conditions. Tests using thick tensile specimens were made to determine the influence of the usage of such primers on the shear stress-shear strain behaviour of the adhesive. Adhesive layer thicknesses of 0.5 mm, 2 mm, 3 mm and 5 mm have been used. The results can be found in Figure 19.

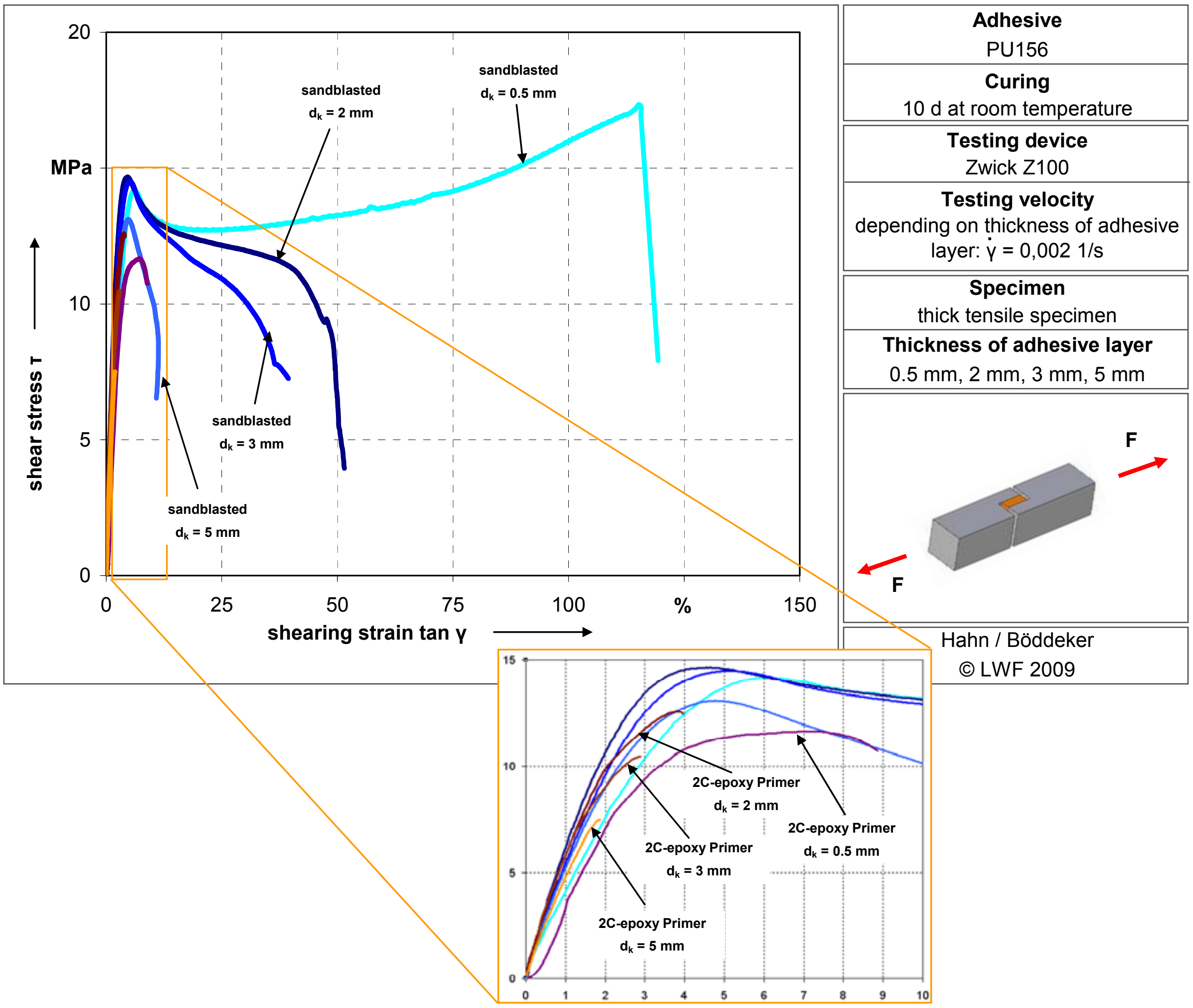


Figure 19: Shear stress-shearing strain behaviour of uncoated and 2C-epoxy coated thick tensile specimens bonded with PU156

Tests show that the influence of the 2C-epoxy primer on the strength of the adhesive is significant. The strength as well as the shearing strain decreased rapidly in using the brushed primer. The bigger the adhesive layer thickness, the lesser the bond strength and the shearing strain. Using an primed specimen and adhesive layer thicknesses of 5 mm leads only to 2 % shearing strain. The shear stresses reach about 7.5 MPa which is less than the half of the values, unprimed specimens could reach. The minor mechanical properties can be explained by analysing the appearance of fracture of the thick tensile specimens. In opposite to the unprimed specimens, a cohesive failure in the primer can be detected. That means the failure of the specimens is not related to reduced bond strength but to a less cohesive strength of the used primer (Figure 20).

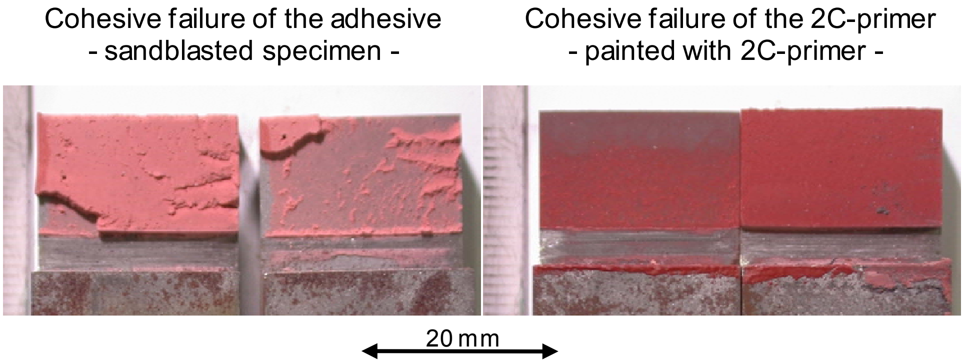
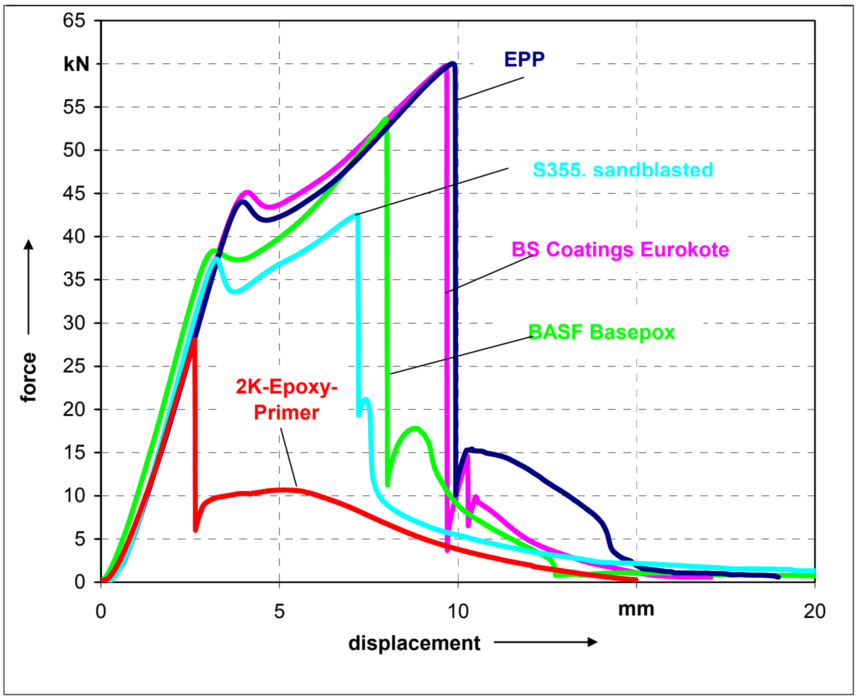


Figure 20: Comparison of the appearance of fracture of uncoated and coated thick tensile specimens

Comparing the appearances of fracture of the thick tensile specimens, it is obvious, that the failure of the specimen displayed on the left can be characterised as a cohesive failure of the adhesive, whereas the specimen on the right side failed due to an cohesive failure of the coating. The same can be seen in using the small scale pipe specimens. A comparison between only sandblasted and all coated pipes can be found in Figure 21.



Specimen small scale pipe specimen
Testing device Zwick Z100
Testing velocity 10 mm/min
Adhesive PU156; cured at RT
Surfaces BASF Basepox PE50-1081; cleaned with C_3H_8O
BS Coatings Eurokote 714.41; cleaned with C_3H_8O
EPP; cleaned with C_3H_8O
S355; sandblasted, acetone cleaned
2K-Epoxy-Primer

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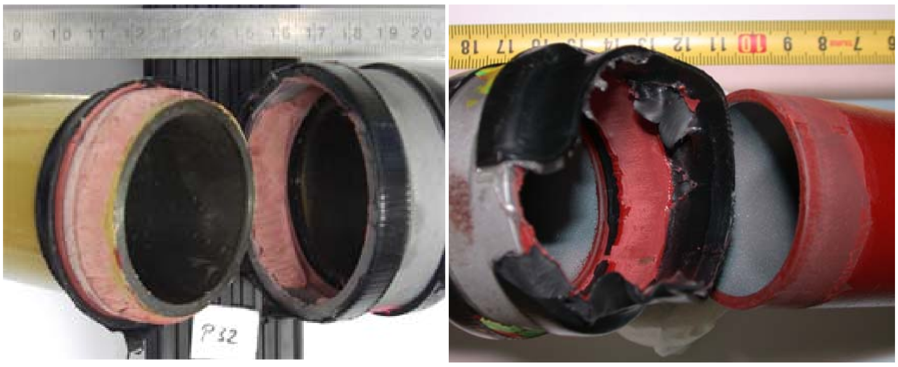
Figure 21: Influence of surface pre-treatment on the strength of adhesively bonded pipes

The specimens, coated with the 2C-epoxy primer show a brittle failure without any plasticity before reaching maximum tensile strength. All specimens coated with epoxy-powder coatings or with an electrophoretic painting, or even the sandblasted specimens could reach significantly higher strength combined with an improved deformability. Figure 22 shows the appearance of fracture of pipes coated with an powder coating and pipes which were coated using a 2C-epoxy primer. Here, a cohesive failure of the 2C-epoxy primer can be attested as well.



Cohesive failure of the adhesive
- sandblasted specimen -

Cohesive failure of the 2C-primer
- painted with 2C-primer -

Figure 22: Influence of different surface pre-treatments on the appearance of fracture

Due to these results it can be stated that the 2C-epoxy primer is not applicable in the field of adhesively pipe bonding.

Hence, the idea, to use a 2C-epoxy primer for coating the pipes subsequently, will not be followed any more. Therefore, it was decided to use sandblasted pipes for the field tests instead of primed pipes.

4.5 Task 1.5: Development of Easy Application Method Including Curing Method

To achieve a cost leadership in the field of pipeline connections, time is an important factor. In particular the time for curing the adhesive has a big influence of the process time in connecting pipes. As 2C-cold curing adhesives are proposed for pipe bonding, curing time of these adhesives might be too long and the pipe laying process might be delayed by the latter. Therefore, a method has to be determined to accelerate the curing process of the adhesive. Two different methods are possible: the first approach is to modify the adhesive’s curing reaction. The second one is to speed up the curing reaction in using heat. As the curing reaction of an adhesive follows an Arrhenius equation, that means, that the time for curing can be halved by increasing the curing temperature by 10 K, curing can be speeded up significantly even in using moderate temperatures. As this task deals with the development of a process for accelerated curing, the possibility of a modified curing reaction of the adhesive will not be followed at this stage.

To get information of the curing of the adhesive in the small pipe specimens, tests were performed with different curing periods. Specimens were cured for 12 h, 24 h, 48 h, 72 h, 96 h and 120 h at room temperature. After these curing periods, tensile tests have been performed. Figure 23 shows the force-displacement curves of specimens which were cured in different time periods.

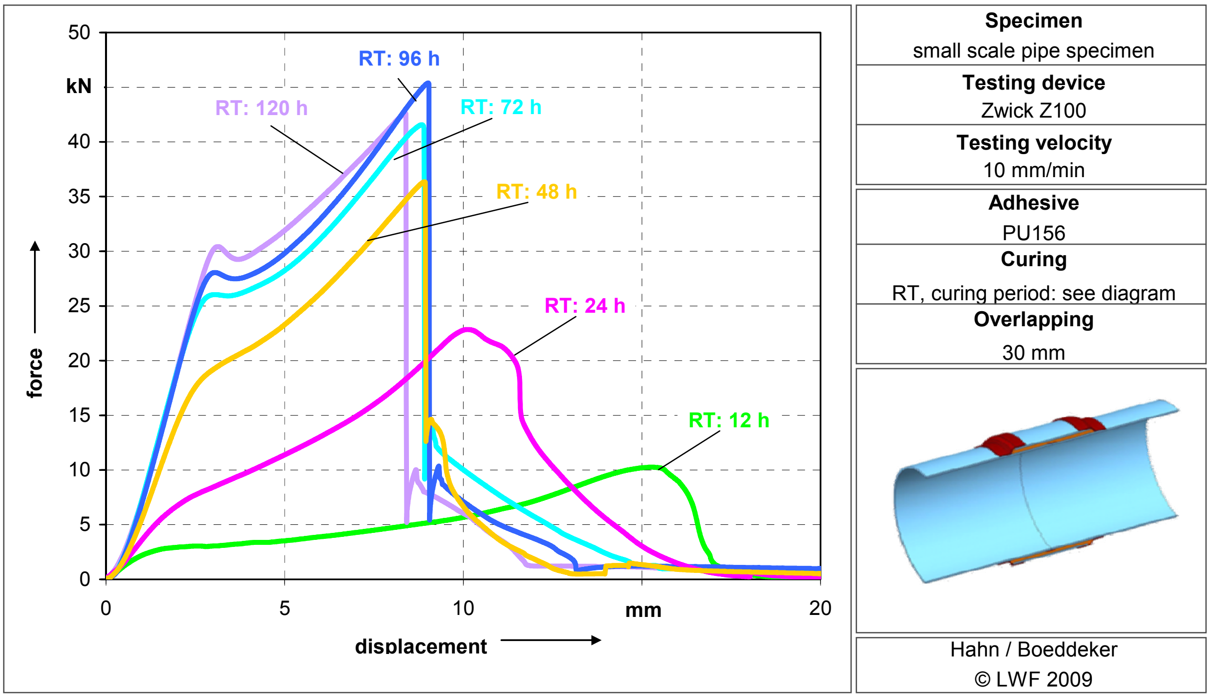
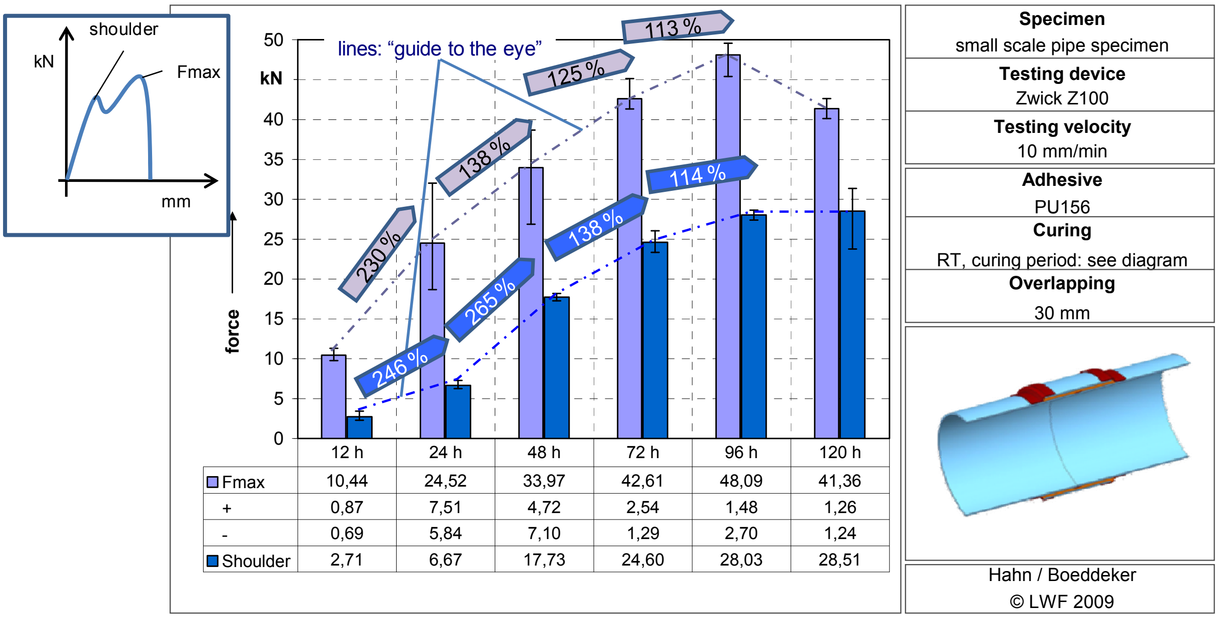


Figure 23: Force-displacement curves of small scale pipe specimens, cured in different curing periods

After 12 h and 24 h of curing at room temperature, PU156 is not fully cured, yet. The bond shows a low stiffness followed by high displacements. After 48 h of curing, the characteristic behaviour, one local force maximum and global maximum force, appears. After 72 h, the adhesive can be defined as fully cured, as no additional strength by further elongation of the curing period can be achieved. This can be seen also in having a look at Figure 24.

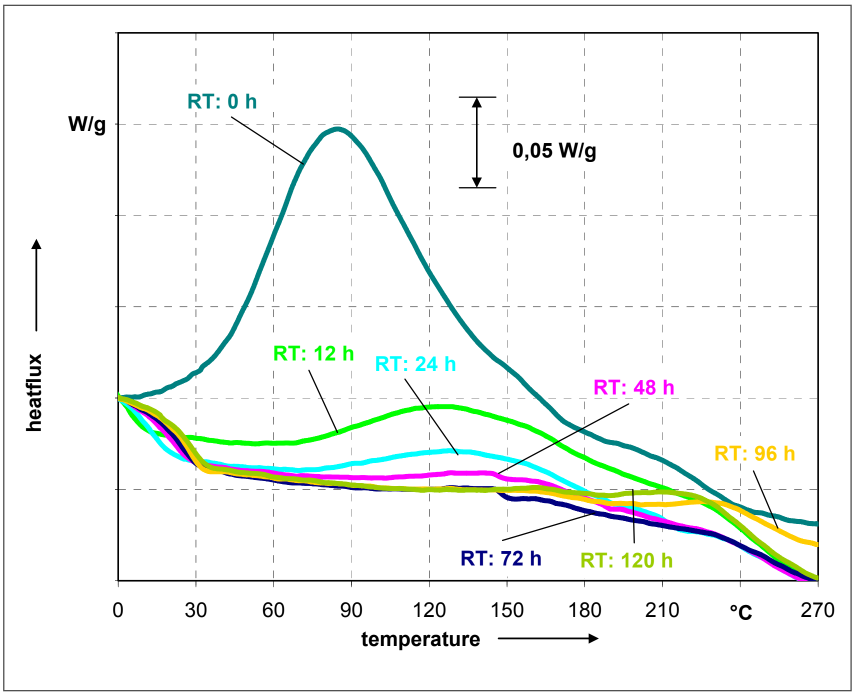


	12 h	24 h	48 h	72 h	96 h	120 h
▨ Fmax	10,44	24,52	33,97	42,61	48,09	41,36
+	0,87	7,51	4,72	2,54	1,48	1,26
-	0,69	5,84	7,10	1,29	2,70	1,24
■ Shoulder	2,71	6,67	17,73	24,60	28,03	28,51

Figure 24: Development of strength of adhesively bonded pipes after different curing periods

It can be seen that strength of the bond and the strength of the shoulder, indicating a first rupture of the adhesive, develops until 72 h of curing. After that, the forces do not increase any more. It has to be assumed that the adhesive is fully cured after this time period.

To characterise the progress of the curing reaction, DSC-analysis have been performed directly after the tensile tests. The adhesive for these tests was educed directly from the adhesive bond line of the small scale pipe specimen. The results of the DSC analyses can be found in Figure 25.



Adhesive	PU156
Testing device	Mettler DSC30 S
Test method	DSC analyses (DIN 53765)
Heating rate	8K/min
Displayed	standardised heat flux
Mass of adhesive sample	40 mg
Specimen	Al-cup (20µl) sample of cured adhesive 

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Figure 25: DSC-analyses of PU156 after different times of curing

Analyses show that the curing reaction of the adhesive has its highest intensity within the first 12 h. After 12 h, the intensity is damped and after 72 h, no heatflux coming from the adhesive bulk can be detected.

For accelerated curing, following test setup was used (Figure 26).

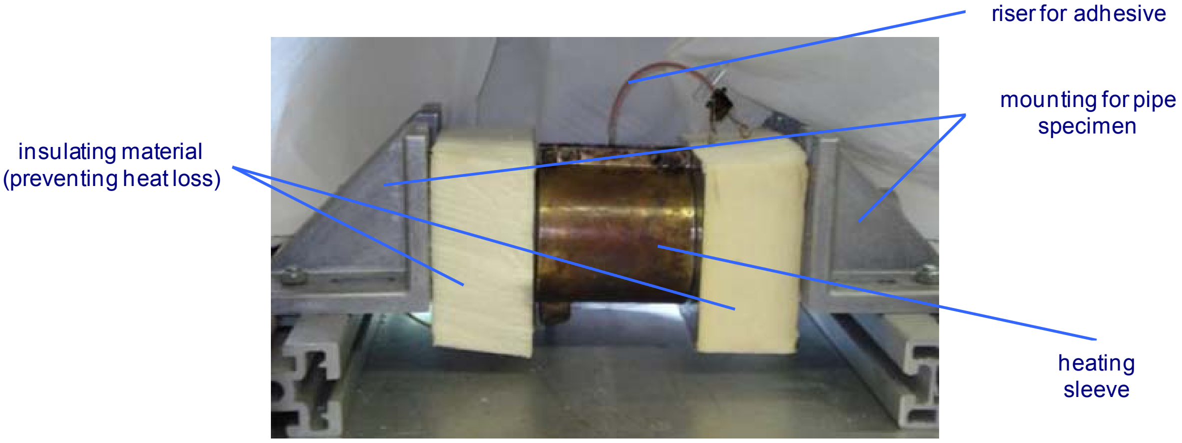

Figure 26: Test setup for accelerated curing

The test setup consists of an electrical heating sleeve, insulating material to prevent an intensive heat loss and a mounting for the pipes. The temperature of the heating sleeve was continuously logged by a thermocouple. A PID-controller adjusted the temperature of the sleeve until the curing period was completed.

First results in curing small scale pipe specimens with a temperature of 60 °C are displayed in Figure 27.

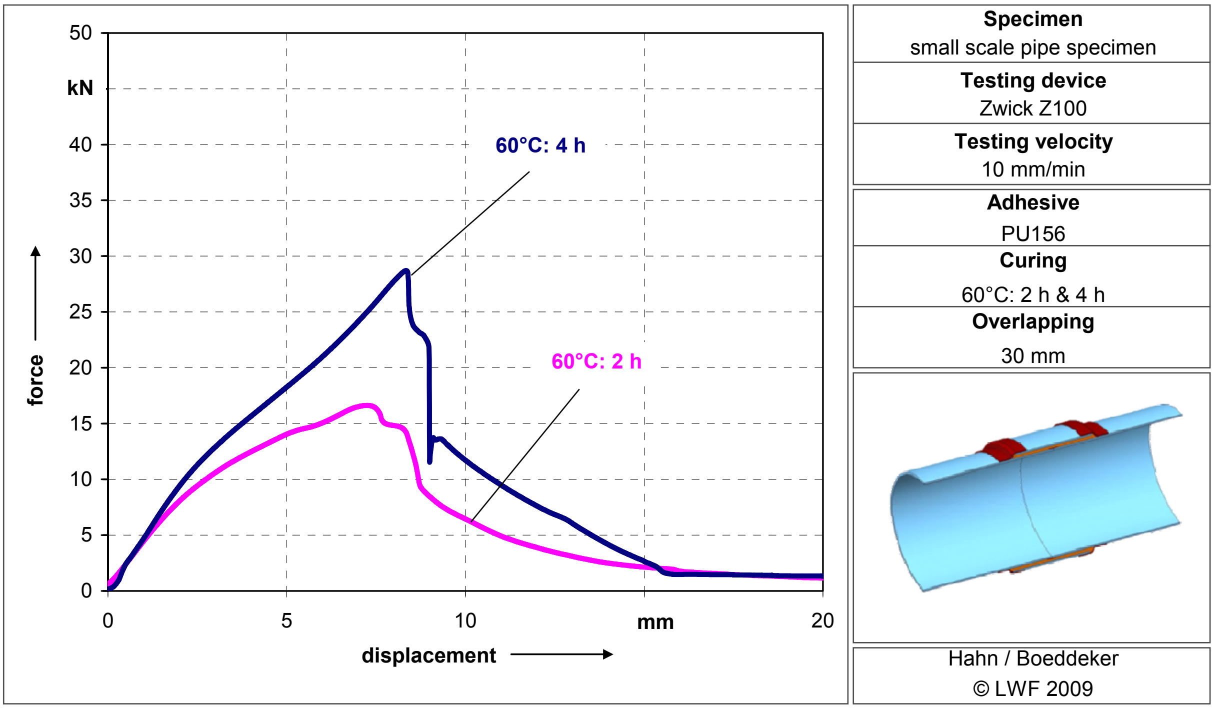

Figure 27: Force-displacement curves of accelerated cured small scale pipe specimens after 2 h and 4 h curing at 60 °C

Results show that accelerated curing of adhesively bonded steel pipes is possible. After 4 h of curing at 60 °C nearly the same strength could be reached as for curing the adhesive for 48 h. Therefore, results seem promising. Curing tests with longer curing periods and higher temperatures will be performed.

5. WORK PACKAGE 2: QUALIFIKATION OF PROCESS FOR FIELD CONDITIONS AND REQUIERED PROCESS QUALITY CONTROL

5.1 Task 2.1: Development of a Quality Control System

The ultrasound techniques developed to ensure a non-destructive quality control of adhesively bonded pipe joints were further qualified using plate joints. All relevant defects as artificial air voids, PTFE stripes and foam, which may be generated by contact of the adhesive with water, could be clearly detected.

A closer investigation of real defects (air voids) showed that they are covered towards the steel with a thin adhesive layer. Thus, artificial defects with a covering layer were made. Experiments with samples of varying layer thickness between 25 µm and 500 µm showed that even these voids can be found if the inspection parameters are chosen properly. With a further set of samples it was investigated if voids that do not fill the complete gap, but are located even deeper in the adhesive (Figure 28) may be detected. Here again it was found that the defects can be identified if measurement and evaluation parameters are set properly.

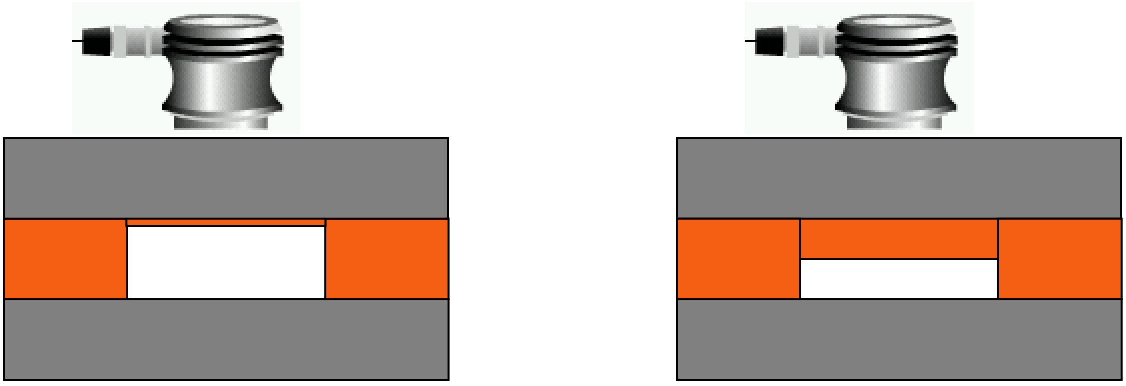

Figure 28: Air void in the adhesive with thin layer to the inspection side filling the width of the gap (left). Air void in the lower part of the adhesive (right).

Next, the influence of different wall thicknesses was investigated using a step wedge sample. It was found that variations in wall thickness have only a minor influence and do not prevent a successful inspection.

As a conclusion all relevant defects can be detected with the developed quality control technique in one single inspection run.

The transfer of the technique from plate to pipe material was done. It turned out that for a reliable inspection good quality sleeves are absolutely necessary. The local out-of-roundness has to be small to ensure homogeneous testing conditions, while an overall ovality of about 2 % can be accounted for. Thus, the self made sleeves that were tried were not suitable for the inspection. First test with new sleeves ordered showed good inspection capabilities.

A test pipe of diameter 168 mm was prepared with two artificial air voids and tested with particular mechanics on a modified lathe. Again, the defects with and without covering layer could be well detected (Figure 29)

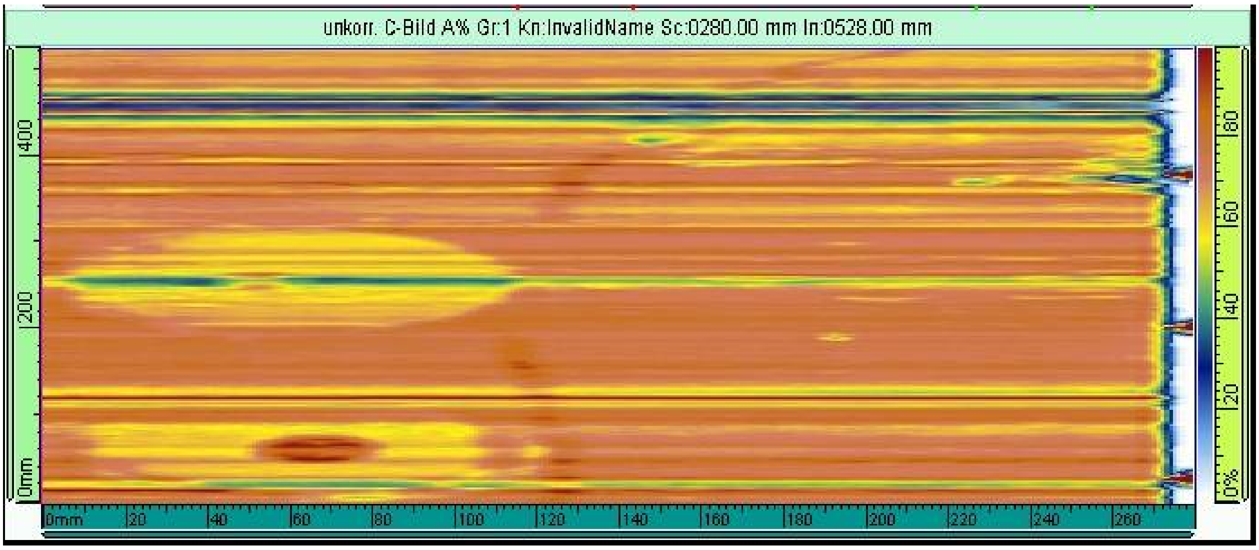

Figure 29: Inspection result of artificial air voids with and without covering layer. Both defects can de detected clearly.

Finally the use of EMAT-technique was tested as it allows the generation of ultrasound by electromagnetic forces. Thus, no water as coupling medium is necessary what facilitates the handling on site. As these tests were successful, the inspection of bonded joints within the scope of this project is done using the EMAT-technique before further destructive tests.

5.2 Task 2.3: Transfer to field conditions

The developed joining method, which has been tested using the designed small scale pipe specimen, was transferred to be used with pipeline relevant pipe geometry OD = 168.3 mm pipes.

For performing these transfer, first a device has to be build which allows to align the pipes to each other and which lets space for working on the pipes' ends and on the sleeve. For this purpose, an I-beam with a block-out was used. Four plates were welded at the upper side of each side of the flange to fix the pipes to be laid on them (Figure 30).

Figure 30: Device for centring and aligning steel pipes for adhesively bonding

In a second step, sleeves had to be manufactured to be used as auxiliary joints. Therefore, the pipes were cut and widened using specially manufactured devices (Figure 31).

Figure 31: Widening of the sleeves

A spacer was welded into the appearing gap, to get a closed geometry. For injecting the adhesive, filling ports were screwed into the sleeve. Hose clamps were used to connect hoses to the filling ports. The pipes were grinded and cleaned with acetone. A two component primer was used to act as a corrosion protection and applied to the pipes using a brush. After curing of the primer, the abutting faces were sealed using a polyurethane based sealant (Figure 32).

Figure 32: Aligned and surface pre-treated pipes, sleeve not centred

For centring the pipes, steel wedges were used as proposed in the joining concept. For sealing the adhesive gap, adhesive tape was used. In Figure 33 a pipe specimen ready for adhesive injection is shown.

Figure 33: Pipe specimen prepared for adhesive injection

After pipe preparation, the adhesive was injected using manually driven cartridges, which were filled with the mixed adhesive components. After this first trial, the specimen was cut into pieces and the bondline was examined. Widening of the sleeve leads to an uncylindrical adhesive layer. At the top of the bondline, an air bubble emerged. In next steps, through modifications of the adhesive outlet and of the equipment for bulging out the sleeve, these mistakes could be prevented.

6. WORK PACKAGE 3: FULL SCALE TESTING OF ADHESIVELY BONDED PIPE JOINTS

6.1 Task 3.1: Full Scale testing

6.1.1 Internal hydrostatic pressure tests

a) Specimen

To prove the ability of the adhesively bonded joint to resist inner pressure under operating conditions, multiple hydrostatic pressure tests were performed. Therefore several specimens have been manufactured at SZMF (Salzgitter location). These specimens were made of two pipe pieces with a length of 1000 mm and dimensions OD 168.3 x WT7.1, which were adhesively bonded. The sleeve for this bond had a length of 550 mm with dimensions OD193.7xWT8.0 mm. Pipes and sleeve material was S235JR. The resulting gap for the adhesive between pipe and sleeve was about 5 mm. The ends of the pipes were closed with semi hemispherical caps. Figure 34 shows a sketch of the specimen, which is not to scale.

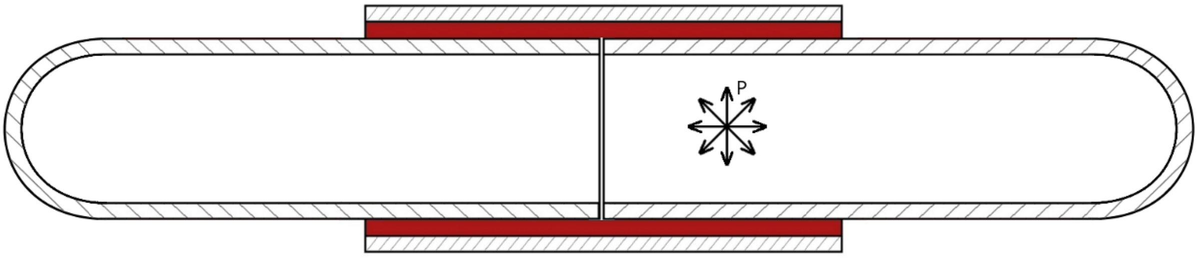

Figure 34: cross section of a specimen

b) Computed Failure Modes

1. Burst Pressure

To calculate the maximum reachable burst pressure, tensile tests with the pipe material have been performed. The yield strength of the pipe has been determined to Y = 334 MPa and the tensile strength to T = 418 MPa. Using the following values:

D_a = 168.3 mm , outer pipe diameter
D_i = 154.1 mm , inner pipe diameter

the burst pressure can be calculated using the formula of Staat:

$$p_{comp} = \frac{2}{\sqrt{3}} \sigma_{fail} \ln u .$$

With $\sigma_{fail} = \frac{1}{2}(Y + T)$ and $u = \frac{D_a}{D_i}$. The computed burst pressure is:

$$p_{comp} = 383 \text{ bar} .$$

2. Axial Force

The above calculation is based on the assumption that the joint can resist this pressure and the bonded pipe is the component that fails.

On the other hand the adhesive could be the part that fails. The maximum allowable axial force for the adhesive is calculated on the assumption that the adhesive bond distributes the stress equally over the surface. Due to the equilibrium conditions we have to take only half of the glued length into account. By using the following values:

D_a = 168.3 mm , outer pipe diameter
l = 275 mm , half of the glued length
τ_{max} = 15 MPa , maximum shear stress for the adhesive

The maximum allowable axial force is:

$$F_{max} = D_a \cdot \pi \cdot l \cdot \tau_{max}$$

F_{max} = 2181 kN

The maximum generated axial force by the computed burst pressure p_{comp} = 383 bar and an inner pipe diameter of D_i = 154.1 mm would be:

$$F_x = p D_i^2 \pi / 4 = 714 \text{ kN}$$

Consequently, the axial force from the hydrostatic pressure should not lead to a destruction of the bonded joint. From the theoretical computational point the steel pipe should be the part that fails.

b) Hydrostatic Testing Equipment

The hydrostatic pressure tests were performed with inhibited water. To build up the required pressure, a hydraulic pump with a volume flow of Q = 0,75 l/min and a maximum reachable pressure of p_{pump} = 4500 bar was used. The connections were made of hydraulic pipes with Ermeto cutting ring connections. To detect the pressure, a transmitter with a range of p_{mess} = 3000 bar was used. The applied volume was measured by calculating the water pumped out of a tank connected to a scale.

c) Test Set-up

The specimen was placed into the burst pit and connected to the pump and the pressure transmitter. The pump was connected to one side of the specimen and after filling and venting, the transmitter was connected to the other end. The specimen was placed into a protective pipe in case of shrapnels after pipe burst. Figure 35 shows the schematic setup of the test.

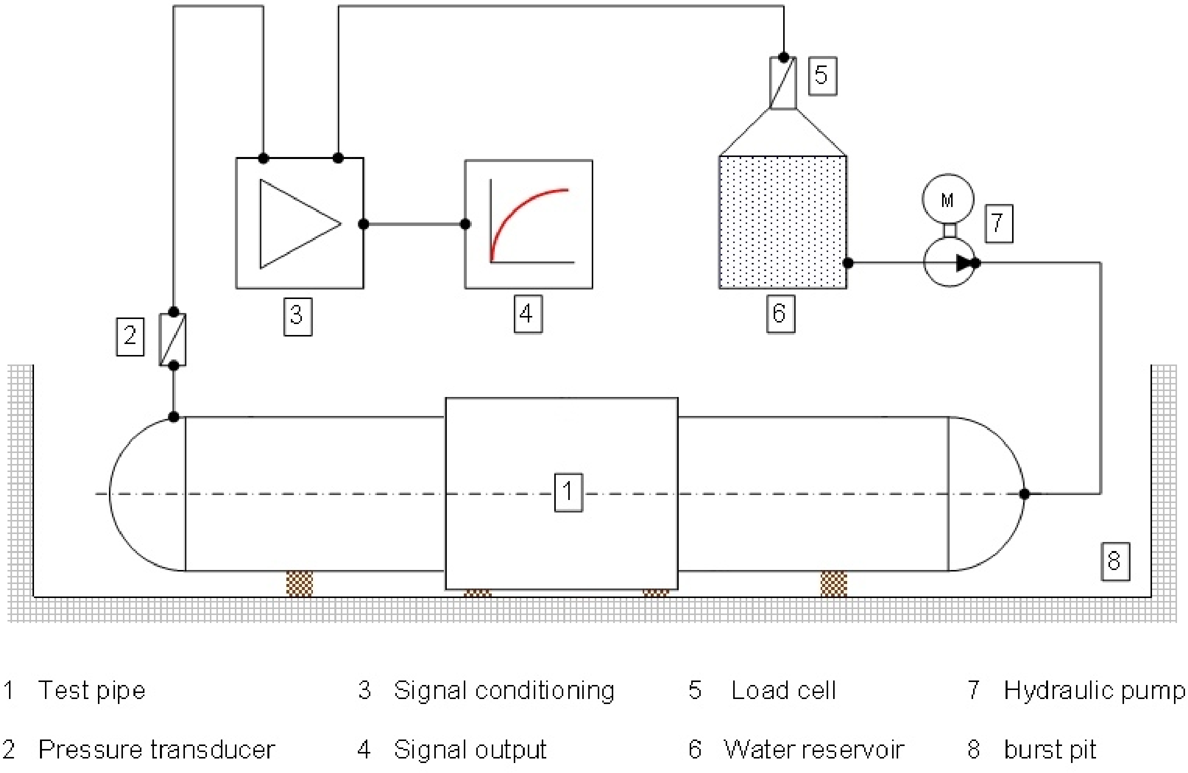

Figure 35: Principle of a hydrostatic burst test

d) Internal Hydrostatic Pressure Test No. 1

In this very first pressure test, the specimen was filled with water and vented. Then the pressure measurement was connected and the pressure was increased as shown in the pressure volume diagram in Figure 37. The specimen became permeable before the computed burst pressure p_{comp} = 383 bar was reached. At p_{max} = 87 bar a leakage through the adhesive layer emerged (Figure 36).

Figure 36: Leakage of specimen no. 1

The volume-pressure curve (Figure 37) first shows a linear increase up to the maximum of p_{max} = 87 bar. From this point, the curve decreases rapidly till it reaches 40 bar from where it converges to a constant pressure of p_{test} = 35 bar due to the constant volume flow of the pump.

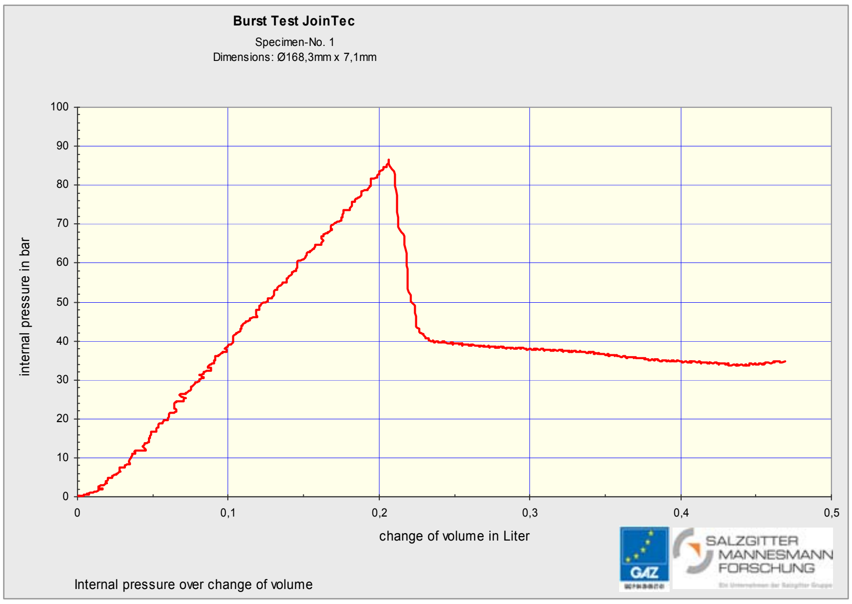

Figure 37: Internal pressure over change of volume from specimen no.1

e) Internal Hydrostatic Pressure Test No. 2

For the second test, the next specimen was filled with water and vented. The pressure measurement was connected and the pressure was increased as shown in Figure 39. The second specimen also became impermeable before reaching the computed burst pressure. At p_{max} = 67 bar a leakage emerged through the borehole of the adhesive inlet (Figure 38).

Figure 38: Leakage of specimen no. 2

The volume-pressure curve of this test (Figure 39) also shows a linear increase of the pressure until the maximum of p_{max} = 67 bar. After reaching the maximum, the pressure decreases until a constant pressure of p_{rest} = 15 bar due to the constant volume flow of the pump.

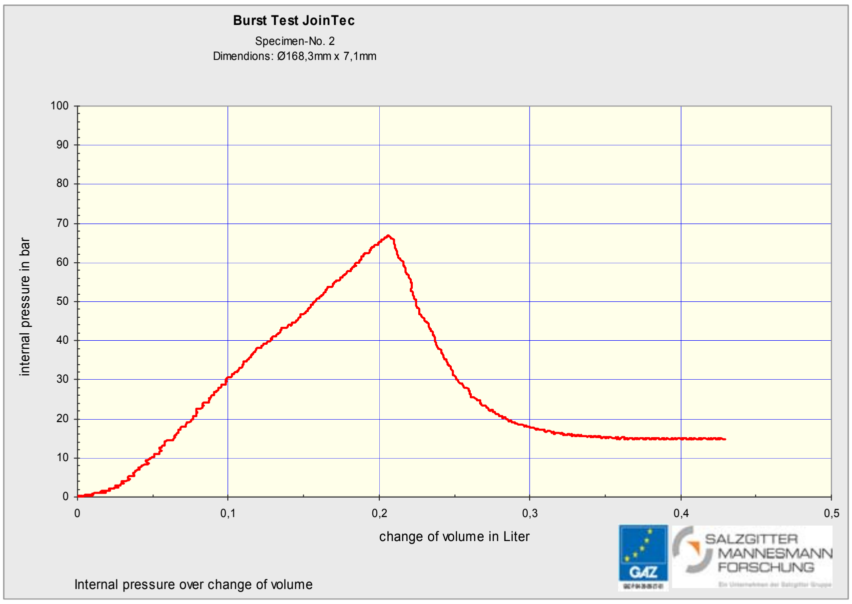

Figure 39: Internal pressure over change of volume from specimen no. 2, first test

f) Internal Hydrostatic Pressure Test No. 2b

To test the further behaviour of the bond and to eliminate a failure due to the borehole, the borehole was sealed and the second specimen was tested again. This time the leakage occurred in the adhesive layer (Figure 40) at a maximum pressure of p_{max} = 40 bar. The low pressure results from the previous damage from the first test with this specimen.

Figure 40: Second leakage of specimen no. 2

Figure 41 shows the volume-pressure curve of the repeated second test. Pressure increases linearly to the maximum of p_{max} = 40 bar, from where it slowly decreases with a constant volume flow to a pressure of p_{rest} = 27 bar.

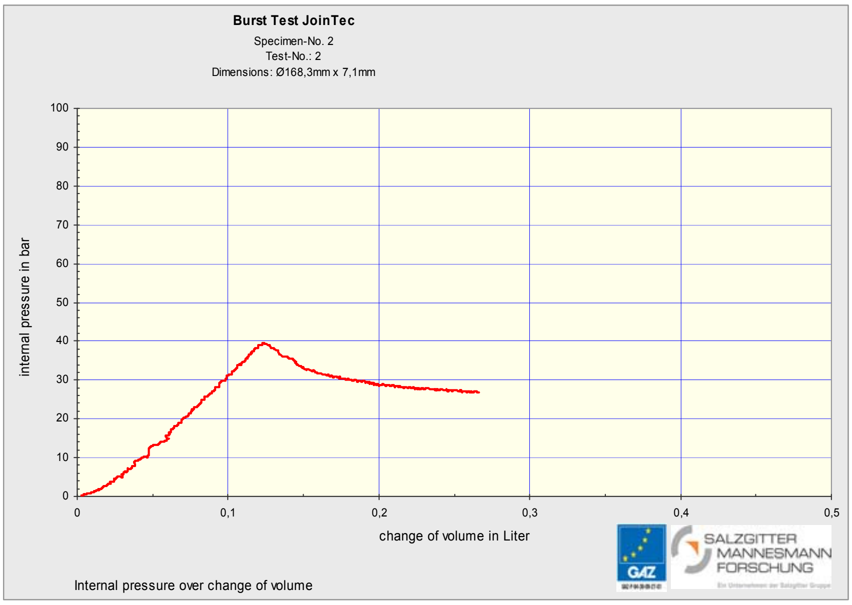

Figure 41: Internal pressure over change of volume from specimen no. 2, repeated test

g) Discussion of Internal Hydrostatic Pressure Tests No. 1 and No. 2

The first two specimens did not reach the pressure values that have been expected by this joint. The first explanation for this early failure of the adhesive bond was the unfavourable load case for the adhesive, see Figure 42. The maximum inner pressure reached generates an axial force of $F_x = pD_i^2\pi/4 = 162\ \text{kN}$ which causes a shear stress in the adhesive layer of $\tau_p = F_x/(D_a\pi \cdot l) = 1.12\ \text{MPa}$. The second load case is the effect of the hydrostatic pressure directly onto the adhesive of $\sigma_n = 8{,}7\ \text{MPa}$. These two loads merge in an equivalent von Mises stress of $\sigma_v = 8.91\ \text{MPa}$. This stress should not be the reason for the failure of the adhesive, which has nominal shear strength of $\tau = 15\ \text{MPa}$.

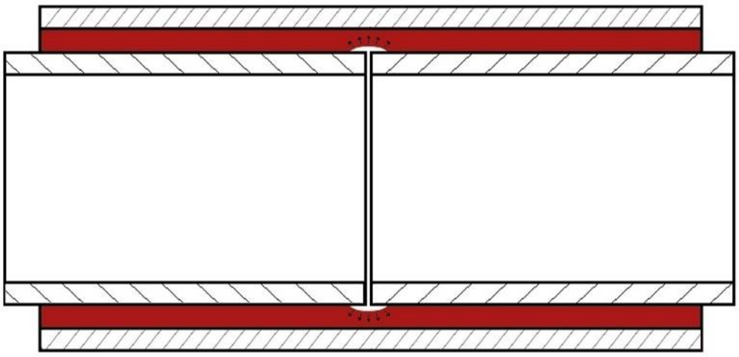

Figure 42: Unfavourable load case

After sawing the tested specimens, it turned out that the adhesive was not completely cured (Figure 43). This was caused by the resin component of the adhesive. The solid parts of the component have settled down in their container, thus leading to a non stoichiometric mixture of the adhesive. This circumstance in connection with the unfavourable load case was the main reason for the early failure. In further small scale tests it also turned out that pipes treated with a 2C-primer can hold less than untreated pipe specimens.

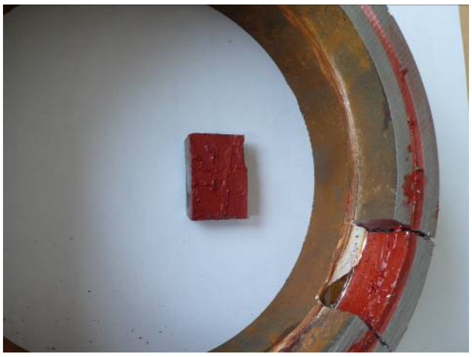

Figure 43: None cured adhesive

The problem with the non cured adhesive was solved by stirring the resin before mixing it with the hardener. Additionally, the next specimens were manufactured without primer.

h) Internal Hydrostatic Pressure Test No. 3

The third specimen again was filled with water, vented, connected to the pressure measurement and the pressure was increased as shown in Figure 45. This time the hydrostatic pressure reached a maximum of $p_{max} = 109\ \text{bar}$. The leakage emerged in the adhesive layer (Figure 44).

Figure 44: Leakage of specimen no. 3

The volume-pressure curve of the third test (Figure 45) shows a linear increase to the maximum pressure of $p_{leak} = 109\ \text{bar}$. After this point, the gradient of the curve decreases although the pressure further increases until it reaches $p_{top} = 119\ \text{bar}$.

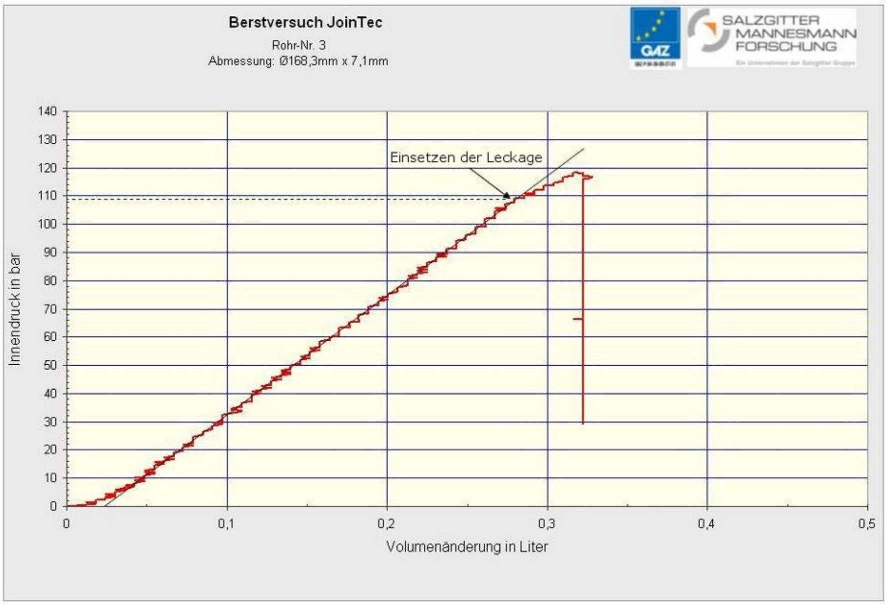

Figure 45: Internal pressure over change of volume from specimen no. 3

l) Internal Hydrostatic Pressure Test No. 4

The fourth specimen was filled with water and vented. After connecting it to the pressure measurement the pressure was increased as shown in Figure 47. It failed at a maximum pressure of $p_{max} = 38\ \text{bar}$ and multiple leakages emerged.

Figure 46: Leakages of specimen no. 4

The corresponding volume-pressure curve (Figure 47) shows two curves. The first one is the actual pressure test. The pressure increases linear to the maximum of $p_{max} = 38\text{ bar}$ from where it drops rapidly to a pressure of 26 bar where the pump was switched of. Afterwards a bigger pump with a volume flow of $Q = 2\text{ l/min}$ was used to test the ability of the leaked adhesive to hold a constant pressure. This can be seen in the second curve which increases to $p_{top} = 55\text{ bar}$ from where it slowly descends to a pressure of $p_{rest} = 28\text{ bar}$.

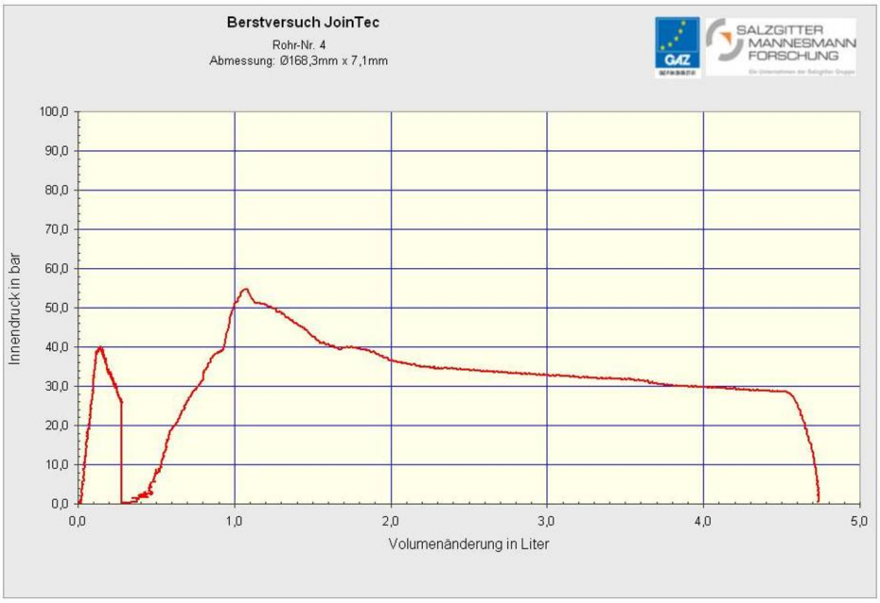

Figure 47: Internal pressure over change of volume from specimen no. 4

An overview of the results of the 4 static internal hydrostatic tests is summarized in Table 2.

Table 2: Results of the static internal hydrostatic pressure tests

Specimen-No.	position of leakage	maximum pressure p_{max} [bar]	possible failure mode
1	adhesive layer, south*	87	not cured adhesive, unfavourable load case
2a	borehole for filling	67	not cured adhesive, unfavourable position for borehole
2b	adhesive layer, south	40	not cured adhesive, unfavourable load case
3	adhesive layer, south	109	unfavourable load case
4	adhesive layer, both sides	38	unfavourable load case, lateral cracks from shrinkage

*north: pressure inlet / south: side of pressure measurement

j) Discussion of Internal Hydrostatic Pressure Tests No. 1 and No. 2

The cross section of specimen no.3 showed no irregularities (Figure 48). There where only a few bubbles, but they could not be made responsible for the leakage. After sawing the fourth specimen one could see some lateral cracks in the adhesive layer. These defects seem to be the reason for the early permeability of the fourth specimen.

Figure 48: cross sections of specimen no. 3 (left) and 4 (right)

The two test series showed that, without a change in the structure of the adhesive layer, pressures of more than 109 bar can not be guaranteed. A conspicuous variety of pressures arose in the first four tests. Hence no well founded conclusion could be derived for a reasonable maximum operating pressure. The first proposal to solve this problem was that there must be a change in the load case of the adhesive to maintain consistent test results. Therefore, two sides of the adhesive layer have to be separated to change the load case into pressure stress (Figure 49). To ensure the impermeability of the joint, the adhesive itself has to be impermeable.

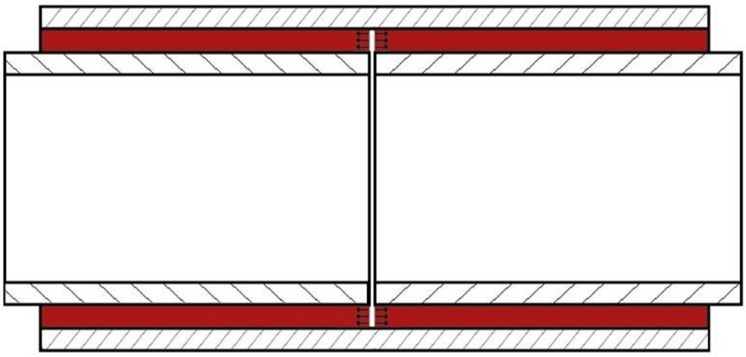

Figure 49: Improved load case

As realizing this gap also meant some extra work in constructing and assembling, an additional sealing is a more promising solution.
Thus, several different sealing variants were worked out and their pros and cons have been compared. The next part gives a short summary about some of these variants.

6.1.2 Development of an Additional Sealing

To guarantee a higher working pressure, an additional sealing technology was developed. Different proposals were discussed, which are briefly summarized in the following section.

a) Sealing on Abutting Faces

The first idea was to seal the two pipes on their abutting faces with an o-ring (Figure 50). The geometry of slots in the pipe is simple and can be made by the pipe manufacturer during end treatment of the pipes. The correct preload for the o-ring is ensured by the ends of the pipes. Cons are that an alignment of the pipes to ensure the correct sealing, which is very difficult, no angular or lateral misalignment must appear. The remaining wall thickness in the slot area is very small and pipes must be machined. This kind of sealing can’t be realized on the construction site without a huge additional machining effort and strict compliance to instructions.

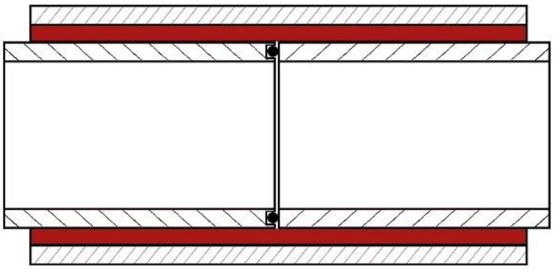

Figure 50: Sealing on abutting faces with o-ring

b) Sealing on Outer Diameter

Alternatively the sealing can be made on the outer diameter of the pipes (Figure 51). But to ensure the correct position of the o-rings slots have to be machined either into the sleeve or the pipes. Slots in the sleeve will reduce the wall thickness in a way that the maximum pressure would be affected negatively, whereas slots in the pipes will not have this effect due to the equilibrium conditions of the pressure inside and outside of the pipes. An Advantage of this variant is that the correct alignment of the pipes is ensured by the o-rings and a small angular misalignment can occur. Disadvantages are that the pipes must be machined and that this sealing is difficult to manage on the construction site. Another undesirable effect is that the transported medium can get onto the outside of the pipe.

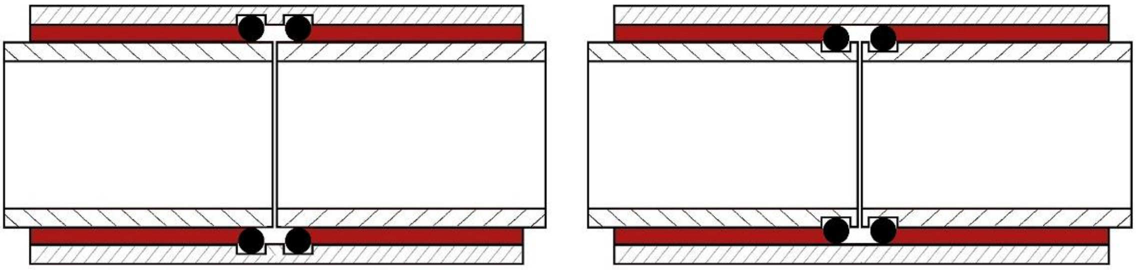

Figure 51: Sealing on the outer diameter

c) Sealing with x-ring

To minimize the need of machining, one variant could be to seal the pipes on their abutting faces only with a big x-ring (Figure 52). This would also allow little angular misalignment and the medium is kept within the pipe. The problem is that there is no standardized sealing in the right dimension available. It is difficult to ensure the correct preload for the x-ring as there is no end stop and under construction site conditions the x-ring could be damaged by squeezing.

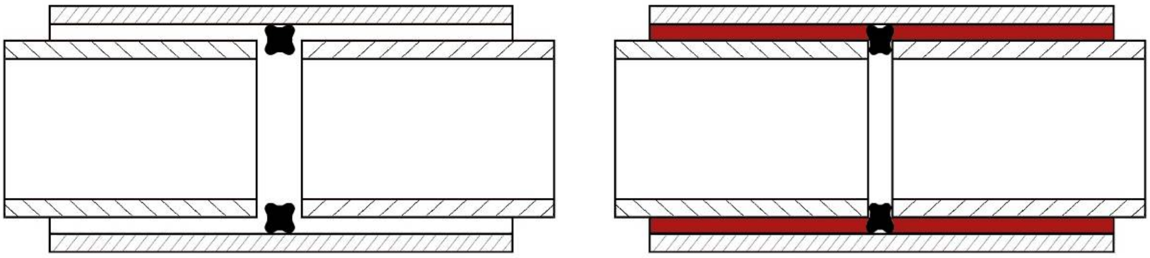

Figure 52: Sealing with x-ring

d) Sealing with Additional Support Ring

The chosen variant is a design using x-rings in combination with an additional support ring (Figure 53). This ring will be placed between the pipes to ensure the alignment of the pipes and the correct preload for the x-ring placed inside the ring. Pros are that it is easy to assemble, standardized seals can be used and no major work on the pipes is necessary. Disadvantages are that an additional ring is needed which requires material and machining and the pipes must be fixed as long as the adhesive is not hardened to ensure the correct angular alignment and preload on the x-ring.

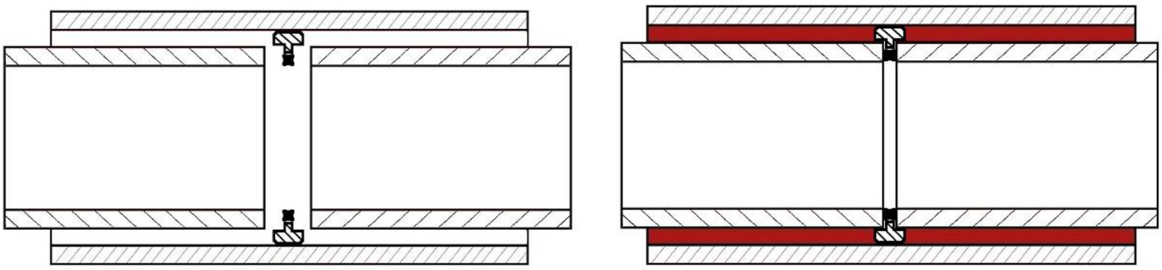

Figure 53: Sealing with additional support ring

Nevertheless this solution seems to be most promising and is used for the next tests to ensure a higher operating pressure. The high differences in pressure for the case of impermeability shown in the first test should be reduced significantly.

6.1.3 Future work

The next test series contains two specimens with additional sealing for internal hydrostatic pressure tests and one specimen with sealing for an internal cyclic hydrostatic pressure test (swell test).

Tensile tests with pipes of the same dimension ($168.3 \times 7.1\,\mathrm{mm}$) will be performed as well as torsion tests.

Hydrostatic pressure tests and swell test with pipes of the dimension OD 508.0 × WT 9.0 mm are planned. The table summarizes the upcoming tests.

Table 3: Test program full scale tests SZMF

Pipe Dimension	Type of test	Number of tests
168.3 x 7.1 mm	Hydrostatic pressure tests	2
	Cyclic hydrostatic pressure tests	1
	Tensile tests	3
	Torsion test	2
508.0 x 9.0 mm	Hydrostatic pressure test	2
	Cyclic Hydrostatic pressure tests	2

7. WORK PACKAGE 5: CO-ORDINATION

On 3rd and 4th June 2009, the fifth co-ordination meeting of project partners took place at the Sika Danmark site in Fredensborg, Denmark. The results achieved were discussed and the next steps in the project were determined.

As the construction Company Bohlen & Doyen is not part of the project team any more, it was asked to get an elongation of the project, to be sure, to fulfil the obligations left behind from Bohlen & Doyen properly.

In addition, it was decided to change the co-ordinator of the JoinTec project from Prof. Hahn to Mr. Boeddeker, who is already working on the JoinTec project.

8. NEXT STEPS

The next steps in the JoinTec project are as follows:

A test series for bonding pipes and laying under field conditions has to be elaborated and realised in a co-operation of project partners and sub-contractors. The full-scale tests on medium sized pipes have to be continued and finalised. The next tests contain two specimens with additional sealing for internal hydrostatic pressure tests and one specimen with sealing for a internal cyclic hydrostatic pressure test (swell test). Tensile tests with pipes of the same dimension (OD 168.3 x WT 7.1 mm) will be performed as well as torsion tests. Hydrostatic pressure tests and swell test with pipes of the dimension OD 508.0 x WT 9.0 mm are planned.

Additionally, big sized pipes have to be bonded for full-scale tests. Basing on the results got from bonding of full-scale tests and the finalised tests concerning the processing defects, instructions and guidelines for pipe bonding have to be prepared. The cost comparison between welding and adhesively pipe bonding has to be made.

Optimisation of joint design concerning ageing has to be finalised. Dynamic strength tests on small scale pipe specimens have to be performed.

EUROPEAN COMMISSION
RESEARCH DIRECTORATE-GENERAL

Directorate G – Industrial Technologies
Research Fund for Coal and Steel

ANNEX I

Form 1-1
OBLIGATORY AT THE SUBMISSION STAGE

TECHNICAL ANNEX

Project acronym: JoinTec

Proposal No[2]: RFS-PR-06010

Contract No: RFSR-CT-2007-00035

TITLE:

Innovative and competitive new joining technology for steel pipes using adhesive bonding

OBJECTIVES

WORK PROGRAMME AND DISTRIBUTION OF TASKS

PROGRAMME BAR CHART

EUROPEAN COMMISSION
RESEARCH DIRECTORATE-GENERAL

Directorate G – Industrial Technologies
Research Fund for Coal and Steel

OBJECTIVES:

The general aim of the Research Fund for Coal and Steel (RFCS) is to increase competitiveness of the European steel industry. As pointed out in the "European Steel Technology Platform – Vision 2030" (March 2004) an increase in steel market share can be achieved by the use of new bonding technologies.

Joining techniques such as welding, brazing, riveting and screwing are used by industry all over the world on a daily basis. As a result of the very successful developments in recent years a further method of joining is becoming more and more important and is already a key technology in many areas: adhesive bonding.

The main innovative value of this research work is the introduction of the pace developments in adhesive bonding technology of recent years into the steel pipe industry by means of an interdisciplinary European team work between leading companies and research facilities from the steel and adhesive industry area. The focus of this proposal is on joining steel pipes with a diameter d up to 200 mm (main focus d = 168,3 mm) for water distribution as well as on joining steel pipes with a diameter up to 600 mm (main focus d = 508 mm) for the gas, water and heat transportation. The joining concept will be based on the present pipeline requirements including operation and maintenance processes.

Main objectives:

- Elaborating an efficient, integrated and easy-to-use joining technique for adhesive bonding of steel pipes.
- Development of guidelines, design calculation methods (both analytical and numerical with the Finite Element Method) and non-destructive testing methods including a repair concept for adhesively bonded steel pipes.

Transferability of the elaborated innovative bonding concept including an adequate in-process non-destructive technique for quality control and a repair concept will be verified by pipe laying field tests at the construction site. Additionally, simulation tools for the prediction of the joint's long-term stability will be developed. Furthermore, a detailed cost calculation which will be done at the end of the project to compare this new concept for pipe joints with conventional joining techniques will reveal the economic benefits of this innovative joining concept.

The project team comprises the entire product chain by connecting leading suppliers of both pipes and adhesives with the pipe laying industry and the end users including testing leading institutes for non-destructive and destructive pipe testing and universities as well as umbrella organisations. This ensures an optimal implementation of the developed technology and dissemination of the results. The strong participation of industrial partners reveals the clear industrial interest to carry out the proposed work on European level. The project connects five European countries and eight project partners with complementary profiles. All project partners are leading representatives in their fields of work.

All activities of this project are concentrated on the aim to strengthen the competitiveness of the European steel sector as a whole; at a time where there is an increasing demand on new pipelines for the gas, water and heat distribution. For instance: it is predicted that natural gas consumption will double over the next 20 years. The improvements of living conditions, the global population growth, and last but not least the increasing environmental consciousness is increasing the need for new and safe pipeline constructions.

ANNEX I
Form 1-2
OBLIGATORY AT THE SUBMISSION STAGE

WORK PACKAGE DESCRIPTION	WP No	1

Work package Title	Joining Fundamentals verified on small scale tests	**Number of man hours**[29]
WP Leader	University of Paderborn (UPB)	5200
Contractor	Salzgitter Mannesmann Forschung GmbH (SZMF)	370
Contractor	Gaz de France (GdF)	10
Contractor	Sika Danmark A/S (SIKA)	750
Contractor	Bohlen & Doyen Polska Sp. Z o.o. (B&D)	100
Contractor	Centro Sviluppo Materiali S.p.A. (CSM)	10
Contractor	Mannesmann Fuchs Rohr GmbH (MFR)	10
Contractor	Arbeitsgemeinschaft für Wärme und Heizkraftwirtschaft e.V. (AGFW)	30
Total		**6480**

1 – Objectives

The main objectives of this work package are the following:

- Survey of main requirements, design standards and of main in-service loading conditions in pipe joints in the gas, water and heat distribution net with regard to adhesive bonding.
- Choice of joint design.
- Development of adequate adhesive.
- Selection of economical and technological beneficial surface treatment.
- Development of easy application method including curing method.

2 - Work programme and distribution of tasks with indication of participating contractors

Task 1.1: Survey of main requirements, design standards and of main in-service loading conditions in pipe joints in the gas and water distribution net with regard to adhesive bonding.

At the beginning of the research project the technical specifications and requirements for adhesively bonded joints in the gas, water and heat distribution net have to be defined in close collaboration with all project partners. The pipe laying company B&D (Bohlen & Doyen Polska Sp. Z o.o.) as well as Gaz de France (end user) and the umbrella organisation AGFW (Arbeitsgemeinschaft für Wärme und Heizkraftwirtschaft) will act as consultants in order to provide the other project partners about technical requirements, design standards and their practical experiences and problems in the field of gas, water and heat piping systems made of steel.

This survey including a literature research of the main standard criteria for steel pipe joints forms the foundation for the following tasks. It is also important in order to discuss the geometry of small scale specimens. Simple standard specimens and small scale pipe specimens will be used in this WP. All partners of the WP1 will bring in their individual expertise in Task 1.1.

Task 1.2: Choice of joint design

As the result of adhesive bonding strongly dependents on joint design, choice of adhesive, surface preparation, application method and curing concept it is necessary to research all these areas in order to develop a consistent joining concept. This will be done in close collaboration with the adhesive industry (SIKA).

When switching from welding to adhesive bonding, designs must be reviewed and altered. In principle, adhesive bonded joints could be loaded by three main types of stresses: shear, tension, and peel stresses. The goal is to achieve as uniform stress distributions as possible. Adhesive joints should be designed in such a way that the joint is stressed in shear. Peel stresses should be avoided [26]. Therefore, lap joints are the most commonly used adhesive joints and work best with metal applications because the rigid nature of metal substrates helps to achieve a more uniform stress distribution under shear loading.

Fig. 3 on the following page shows a systematisation of possible joint designs for pipes. Beneficial in terms of adhesively bonded pipes are overlapped and tapered joints as well as joints with a coupler [13] because in these cases the adhesive layer is stressed by shear forces (and torsion). The adhesive butt joint is most probably not the appropriate joint design for pipe applications covered by this project because of the small surface area and the normal stresses in the adhesive layer. The different joint designs with lashings (bushings) always need additional joint devices but offer – similar to overlapping joints - a big surface area for the adhesives. The taper/taper joints have the great advantage in comparison to the other joint designs that the stress peaks in the adhesive layer are avoided [13]. Therefore, in principle these joint designs can transfer higher loads. Disadvantageous is the effort to produce the pipes´ tapered ends. The widened single lap joints are preferred for pipes with small wall thickness due to industrial/economic interests. Generally, the stress peaks in the adhesive layer in overlapping joints can be reduced by chamfers in order to optimise the stress distribution.

In terms of glass-fibre reinforced polymer (GRRP) pipes where adhesive bonding is already used the joint is typically formed using either a bell system (overlapping joint) or a coupler (single lap – outer) [19].

Task 1.2: Choice of joint design (cont´d)

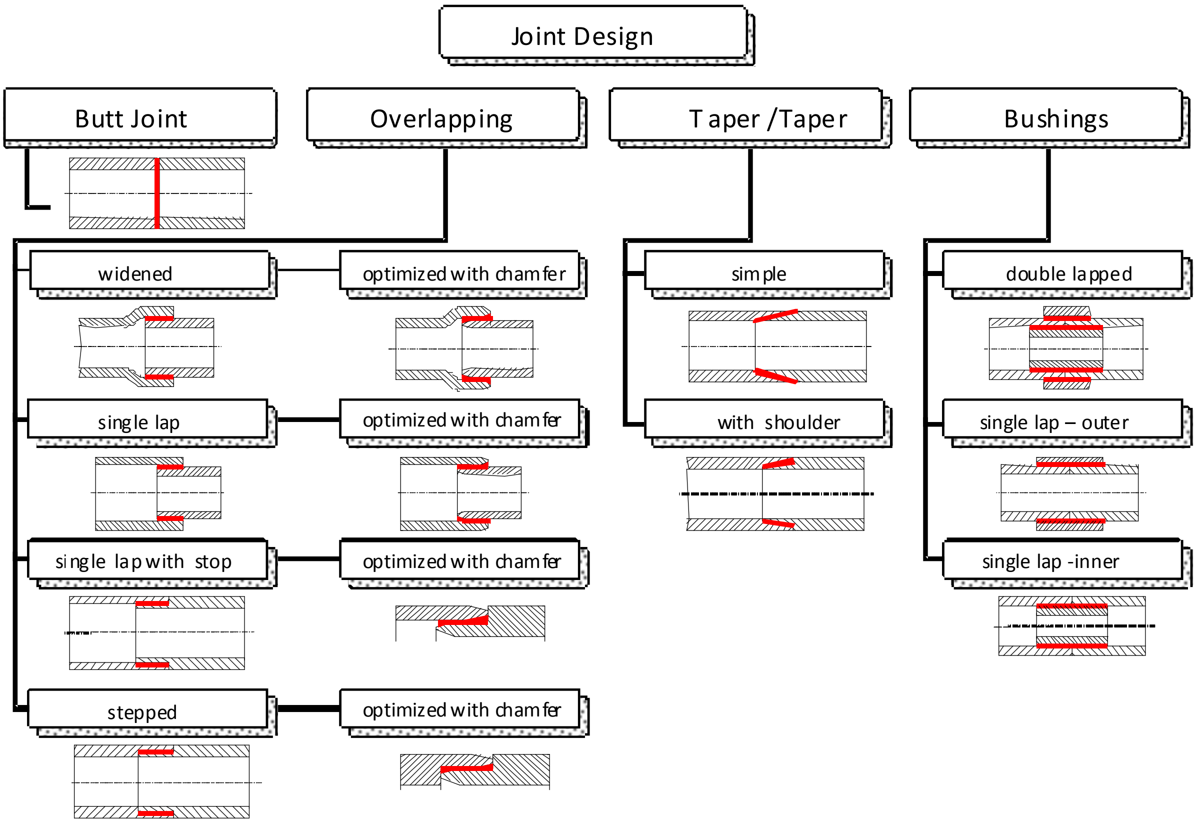

Fig. 3: Systematisation of pipe joint designs [13].

The focus of this new proposal is on joining steel pipes with a diameter d up to 200 mm (main focus: $d = 168{,}3$ mm) for water transportation as well as on joining steel pipes with a diameter up to 600 mm (main focus $d = 508$ mm) for the gas, water and heat transportation. During the last couple of months the project team developed for both the small and large diameter pipes a new, innovative adhesive joint geometry which takes the requirements for a long term use of the pipe (material aging, creep, corrosion) into account. Fig. 4 shows the developed joint design for the large pipes.

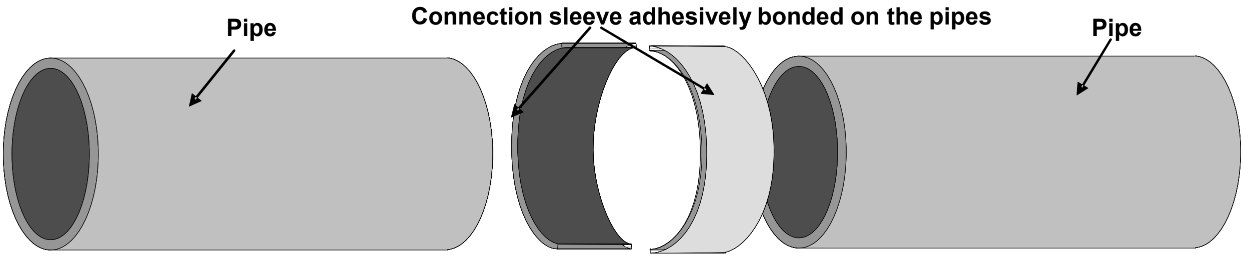

Fig. 4: Developed joint design geometry for steel pipes up to 600 mm in diameter.

The pipes are laid down in a way that they rest against each other. The connection sleeve is divided into two parts in order to ease the joining process. Preliminary stress calculations revealed that the connection sleeve needs a maximum length of 400 mm so that it is overlapping each pipe by 200 mm.

Task 1.2: Choice of joint design (cont´d)

The joint design which will be further evaluated in the research project has to take the present pipeline requirements for operation and maintenance processes (such as piggability and CP for underground lines) into account in order to fulfil the requirements from the end users.

Fig. 5 shows the joint design geometry for the smaller pipes with up to 200 mm in diameter.

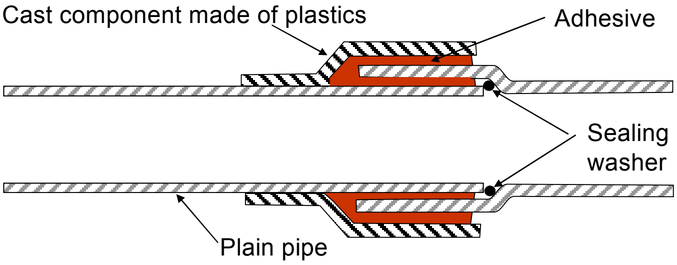

Fig. 5: Developed joint design geometry for steel pipes up to 600 mm in diameter.

The pipe socket which is a cast component made of plastics ensures that the adhesive can be applied easily at the pipe joint. Furthermore, this pipe socket defines the thickness of the adhesive layer. The sealing washers prevent the adhesive from penetrating inside the pipes. Preexaminations done by the project team for the preparation of this proposal pointed out that only an overlapping length of 30 mm is required.

The exact dimensions of these joint geometries will be specified according to the industrial needs by Finite Element simulations (UPB) and by tests on small scale pipes (axial loads, torsion, and pressure) done by SZMF, except dynamic tests which will be done by (UPB). The definition of the exact geometry will be supported by the adhesive industry (SIKA). SIKA will bring in a lot of practical experience since this company supplies already structural adhesives for blade bonding for wind turbines and sandwich panel bonding.

Task 1.2 interrelates with the development of an adequate adhesive. Therefore, on these tasks will be worked simultaneously.

Task 1.3 Development of an adequate adhesive

According to DIN 16920, an adhesive is a non-metal material being able to join adherents by surface adhesion and inner strength. The junction is a result of cohesion and adhesion forces [9]. Engineers can choose the correct product from a great variety of adhesives since 250,000 different adhesives are produced worldwide and about 25000 different adhesive products are available for trade, only in Germany.

Adhesives can be classified in chemically reacting systems and physically reacting adhesives. Chemically reacting adhesives are used for high load assemblies and severe service conditions such as heat, cold or the influence of different mediums. Thus, only chemically reacting adhesives should be considered in this project. In chemically reacting adhesives, there are monomer and pre-polymer molecules ready for reaction in the adhesive layer. They react in the adhesion process with each other under certain conditions, e.g. pressure or temperature, forming polymers in the adhesive splice.

Task 1.3 Development of adequate adhesive (cont´d)

Depending on whether or not the addition of heat is necessary for the curing, chemically reacting adhesives can be divided in cold-setting and hot-setting adhesives. The chemical reactions leading to curing are polymerisation, polyaddition and polycondensation reactions [12, 22], (Fig. 6).

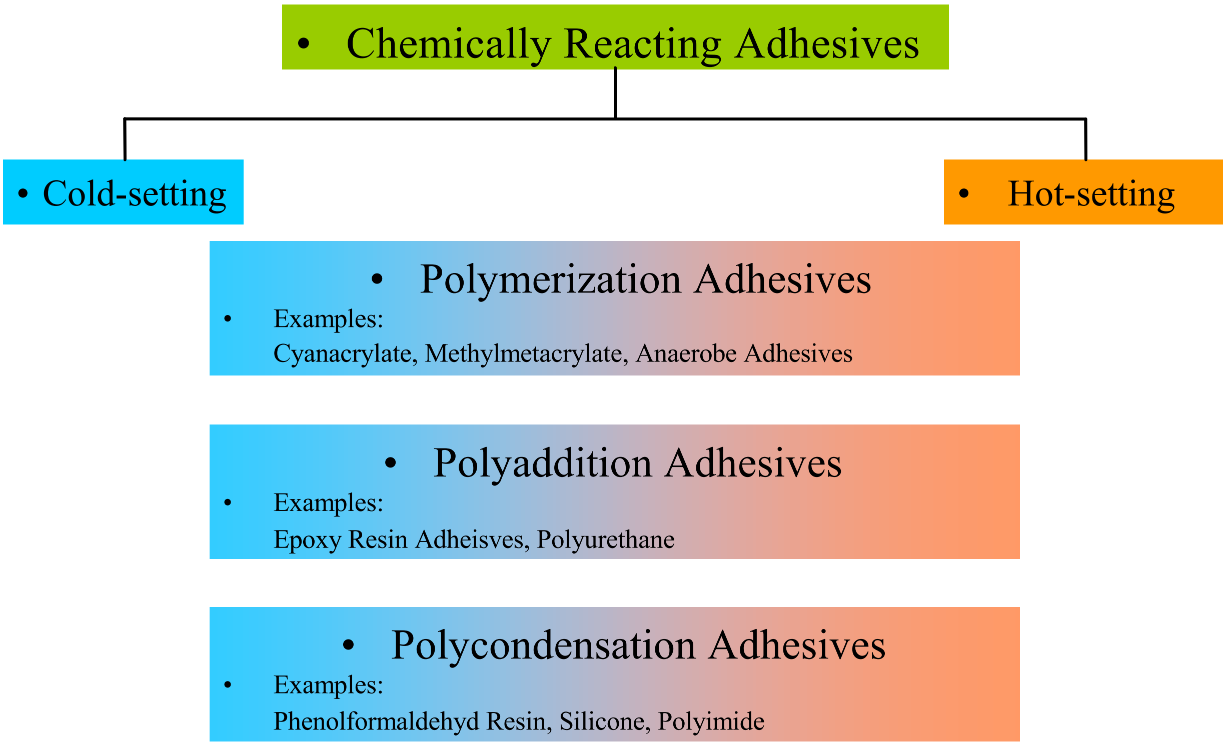

Fig. 6: Chemically reacting adhesives.

For example: polyaddition adhesives based on epoxy resins used in automotive shell construction are hot-setting materials that require temperature above 100°C (212°F) to set. Chemically reactive adhesives can be further subdivided into two groups: one-component systems and two-component systems (mix and no-mix).

One component systems that cure by heat include epoxies, polyurethanes, polyimides and usually consists of two pre-mixed components, which eliminates the need for metering and mixing.

Two component systems come in several forms but usually consist of one part called the adhesive or resin, and a second part called the hardener, catalyst or accelerator. The two components are brought together, i.e. mixed, in a variety of ways, with the mixing starting a chemical reaction, which leads to hardening of the adhesive. Some two component systems do not require careful mixing, such as modified acrylics, in which the accelerator is applied to one surface, adhesive to a second, and the surfaces are joined. Other two-part adhesives, for e.g. some epoxies, often need more accurate mix ratios. Different methods have been developed to help with this mixing, such as pre-measured packs, or cartridges and mixer nozzles. Two component adhesives can cure at room temperature, although some need an elevated temperature to achieve full cure.

Task 1.3 Development of adequate adhesive (cont´d)

Certain technological properties can be achieved by adding different additives and filling materials to the chemically reacting adhesives. New so-called adducts or prepolymers especially suitable for metal bonding have been developed in recent years to further optimise epoxy adhesives [31, 32, 33]. The adhesive formulator can use these components as powerful building blocks in a modular system [2].
Nanotechnology which has become an area of intensive adhesive research in recent years developed methods to synthesise nanosized filler particles which are advantageous in comparison to conventional fillers since much better physical properties of the cured adhesive can be achieved [31]. Recent research even showed that the performance of both one and two component epoxy adhesives can be further improved by combining adducts with these new nanoparticles [31].
For adhesively bonded joints in glass fibre reinforced epoxy (GRE) piping systems used in the oil industry two component epoxy resin adhesives are being used [25]. These GRE-pipes have to resist internal pressures of 100 bar while exposed to water. The most commonly used adhesives for steel joints are epoxy adhesives, modified epoxy adhesives and polyurethane adhesives.

The best adhesive for a given application is generally a function of part design, processing needs and performance requirements. Main performance requirements for this project are durability (material aging, creep, and corrosion), stability against water and gases and an easy handling at the construction site under field conditions. In terms of adhesive bonding of steel pipes which is the scope of this research proposal two component Polyurethanes are the adhesives to be considered. Based on an interdisciplinary research done by the project team as part of the preparation for this proposal the two component adhesive should have an E-Modulus of about 100 MPa, a minimum elongation at fracture of 20 % with a lap shear strength of 10 MPa.

The development and selection of the adhesives will be done by SIKA. This project partner can look back over a long and successful history of structural adhesive bonding and has a great variety of appropriate research capacities. SIKA will approach the project objectives from the chemical point of view.
The selected adhesives will be evaluated by fundamental tests such as adhesion tests, Differential Scanning Calorimetry (DSC) and Dynamic Mechanical Analysis (DMA). This work will be done by UPB. All small specimens tests including shear tests (aged, not-aged), τ-γ tests (aged, not-aged), σ-ε tests (aged, not-aged), dynamic strength tests (Woehler) and impact tests on simple overlapping joints (aged, not-aged) will also be done by UPB. All tests on small pipe specimens – also including tests to optimise the processibility - will be done by SZMF expect the corrosion test (VDA 621-415), the climate tests (P-VW 1200) and tests on small pipe specimens under impact forces. These three tests will be done by UPB. The tests are essential in order to satisfy the industrial requirements for a long term use of the pipeline.
Based on the analysed test results the adhesives will be further evaluated in the WP2, WP3 and WP4. SIKA will supply all project partners with adhesives they need in order to do their work on this project.

Task 1.4 Selection of economical and technological beneficial surface treatment

Surface preparation is very important because the adhesive "only sees the surface". Therefore, the strength of a joint strongly depends on the condition of the surfaces. Surface preparation can range from simple cleaning to extensive anodising and priming. The degree of surface preparation depends on the adhesive used, needed performance and service lifetime. Some adhesives are more tolerant of surface oils and require a minimal amount of surface preparation. In general, a clean dry surface is important for achieving maximum bond strength and repeatable environmental durability.

Main applied preparation methods are:

- Degreasing with steam, organic solvents or alkaline cleaners.
- Mechanical methods such as blasting, brushing or grinding with emery-paper.
- Applying a primer.

It has to be taken into account that the adhesive bonding process has to be done at the construction site under field conditions. This requires a tolerant adhesive bonding process, including surface preparation. Adhesively bonded steel bridges constructed already in the fifties and sixties of the 20th century and still in use have proven that adhesive bonding can successfully be done at the construction site under field conditions [21, 36]. However, in terms of adhesive bonding of glass reinforced epoxy (GRE) piping systems it is reported that the surface treatment done outside at the construction site is sometimes problematic due to the weather conditions. Furthermore, it would be time-consuming.

Therefore, the work should be transferred from outside to inside by doing the surface preparation already in the factory and protecting the prepared joints. This method was already successfully applied in 1963 for another adhesively bonded steel bridge: The steel joints were prepared in the factory by sand blasting, before the surfaces were covered by a corrosion protective coating which had not been removed at the construction site [36].

The objective of this part of the project is to develop and verify an effective, easy-to-use, inexpensive and fast surface treatment for the pipe joints. Such an adequate and efficient surface treatment for adhesive bonding of pipes should be transferred from outside to inside the pipe factories. This has also social benefits as the transfer of surface treatment from outside to inside the pipe factory enables improved working conditions due to controlled temperature, humidity and light conditions together with improved ergonometry by allowing easier access to the pipes.

The selection of the surface treatment, e.g. supply of adhesive tapes will be performed by SIKA. UPB will be in charge of simple adhesion tests and tests to determine the contact angle in order to verify the results which will be discussed by all partners in this WP in order to ensure that the developed surface treatment is also beneficial with regard to the requirements at the construction site.

It is worth noting that all tasks of WP1 interrelate with each other.

Task 1.5 Development of easy application method including curing method

After the surface treatment, the adhesive has to be applied to the joints. There are different adhesive application methods, such as brushing, spraying, dipping, roll coating, knife coating and melting. The adhesive has to be distributed as a uniform film with the correct thickness over the entire circumference. Additionally, it is necessary that the adhesive system accommodate variations in gap at the joint arising from normal production tolerances in order to enable a fast installation process.

A simple idea for the application process is to apply the adhesive with a ring shape at the end of one pipe and before the pipe is inserted into a fitting of the other pipe end. This method is already successfully practiced for adhesive bonding of stainless water tubing [15]. Washers can be helpful for the assembly process. They ensure a defined thickness of the adhesive film over the entire radius. Furthermore, washers can help to easily centre the pipes in the correct position and to prevent that the adhesive leaks from the joint. This method using washers is used for both indoor and outdoor adhesively bonded balustrades in architecture [28].

The focus of this project is to develop a competitive joining technique. For this to be achieved, consideration must be given not only to the base cost of the adhesive (which are very low) but also to the simplicity and cost of application process. In order to reduce the costs in comparison to conventional joining techniques, it is important for the adhesive system to allow installation at a comparable or faster rate. The other boundary condition is that reasonable adhesive cost and ease of installation must be accompanied by satisfying service performance. The joint should function as an integrated part of the pipe.

In order to achieve these objectives different adhesive application concepts have to be evaluated. A most probably very good application method in terms of both from a commercial and technological point of view is to inject the adhesive in the joint area by pressure. The use of washers can keep the adhesive in a defined joint area. It is planned that SIKA will be in charge of the application concept supported by UPB. In order to take the situation at the construction site into account the pipe laying industry Bohlen & Doyen Polska Sp. Z o.o. (B&D) and the end users (Gaz de France) together with umbrella organisations (AGFW) will support the work with their experience and requirements.

3 - Interrelation with other work packages

In work package WP1 a consistent preliminary adhesive bonding concept is elaborated on simplified small scale specimens. The results will be evaluated in detail in the following two packages (WP2, WP3) in terms of full scale tests. Additionally, both a repair and an in-process quality control concept will be developed (WP3). Transferability to field conditions of the results will be verified in WP4 by field tests at the construction site. Furthermore, the evaluated experimental test data obtained in WP1 will be used in terms of the FEM calculation concept of adhesively bonded steel pipe joints under real loading conditions, see WP3, Task 3.2.

4 - Deliverables and milestones

The first deliverable is a compilation of main requirements for adhesively bonded steel pipe joints in terms of economic, loading and environmental requirements. The main deliverable is a preliminary adhesive bonding concept. Information will be available about a fundamental qualification of different adhesives, joint designs, surface treatment concepts and adhesive application methods for steel pipe bonding.

ANNEX I
Form 1-2
OBLIGATORY AT THE SUBMISSION STAGE

WORK PACKAGE DESCRIPTION	WP No	2

Work package Title	Qualification of processes for field conditions and required process quality control	**Number of man hours**[29]
WP Leader	Salzgitter Mannesmann Forschung GmbH (SZMF)	2300
Contractor	Gaz de France (GdF)	20
Contractor	Sika Danmark A/S (SIKA)	30
Contractor	Bohlen & Doyen Polska Sp. Z o.o. (B&D)	80
Contractor	Mannesmann Fuchs Rohr GmbH (MFR)	200
Contractor	Arbeitsgemeinschaft für Wärme und Heizkraftwirtschaft e.V. (AGFW)	10
Contractor	University of Paderborn (UPB)	200
Total		**2840**

1 – Objectives

The main objectives of this work package are the following:

- Selection of an adequate NDT method to develop an in-progress quality control concept capable for the application in the field.
- Repair procedure.
- Transfer of the technologies to field conditions.

2 - Work programme and distribution of tasks with indication of participating contractors

Task 2.1 Development of a quality control system (Non-Destructive-Testing, NTD)

The use of adhesive bonding for the joining of pipes in the field will involve a new demand of in-process quality control. Up to now, adhesively bonded joints for non-critical applications are inspected mainly by random samples. In the scope of the requirements with regard to testing time and the environmental conditions in the field, there is evidence of need for an adequate non-destructive technique.

In general, two types of defects may arise in adhesively bonded joints: Those within the adhesive layer itself, like cracks, porosities, poor curing and precuring defects and spurious materials and those within the proximity of the adherent-adhesive interface like uncomplete filling of the bondline, kissing bonds and delaminations. Depending on the size of the defects, a considerable decrease of the bond strength as well as leaking may result.

Many different non-destructive evaluation techniques have been used to detect cracks and other adhesive defects. Those comprises:

- Ultrasonic techniques.
- Vibration techniques.
- Holographic inspection.
- Radiographic inspection.
- Thermographic inspection.
- And more specialised techniques used in the laboratory scale.

The aim of the this part of the project is to select an adequate NDT method, to develop a detailed inspection procedure and to design a concept for a real application in the field, taking into account all necessary boundary conditions. This leads to limitations in the applicability of some techniques that give suitable results only under laboratory conditions (holographic, radiographic techniques). The transfer of the developed techniques to field conditions has to be insured. The procedure will be as described in the following, concentrating on a one side accessibility:

Laboratory: Use of linear ultrasonic inspection (normal incidence)

This method uses the ultrasonic reflectivity at the interfaces as the observable. The main focus lies on the detection of delaminations at the interfaces adherent/adhesive and imperfections in the adhesive layer (porosity cracks etc.):

Instrumental:

- Choice of suitable transducers on piezo basis (normal incidence) for pulse-echo-mode (wave mode, frequency, geometry).
- Choice of suitable transducers on EMAT basis (normal incidence, no coupling medium) for pulse-echo-mode (wave mode, frequency, geometry).
- Development of suitable laboratory inspection mechanics (probe holder, mounting on the pipe) prepared to allow reliable reproducible and complete testing of the bond in the field.

Task 2.1 Development of a quality control system (Non-Destructive-Testing, NTD), (cont´d)

Ultrasonic inspection of bonded plates and pipes in dependence on:

- Wall thickness of the adherends.
- Adhesive.
- Adhesive layer thickness.
- Surface state and surface preparation.
- Artificial defects in/at the adhesive layer.
- The curing state (during and after curing).

Laboratory: Use of nonlinear ultrasonic inspection (normal incidence)

This technique will use shear waves at high inspection frequencies. It uses the transfer from a base frequency to the higher harmonics in the bond as the observable. The main focus lies on the detection of disbonds, voids and cracking.

Instrumental:

- Careful choice of suitable transducers on piezo basis (high power, very linear behaviour, normal incidence)
- Necessary modification of testing mechanics (expected to be minor).

Ultrasonic inspection of bonded plates and pipes in dependence on:

- Steel grade.
- Wall thickness of the adherents.
- Adhesive.
- Adhesive layer thickness.
- Surface state and surface preparation.
- Artificial defects in the adhesive layer interfaces (especially kissing bonds).

Laboratory: Use of linear ultrasonic inspection (oblique incidence)

This method uses the ultrasonic reflectivity at the interfaces as the observable. The main focus lies on the detection of kissing bonds at the interfaces adherend/adhesive.

Instrumental:

- The choice of suitable transducers on piezo basis (frequency, sound field, geometry, oblique incidence).
- Development of suitable laboratory inspection mechanics (probe holder, adjustment of angle of incidence, mounting on the pipe) adapted to the requirements of oblique angle incidence testing.

Task 2.1 Development of a quality control system (Non-Destructive-Testing, NTD), (cont´d)

Ultrasonic inspection of bonded plates and pipes in dependence on:
- Steel grade.
- Wall thickness of the adherents.
- Adhesive.
- Adhesive layer thickness.
- Surface state and surface preparation.
- Artificial defects in the adhesive layer interfaces (especially kissing bonds).
- Transducer characteristics (angle of incidence, frequency, etc.)

Laboratory: Use of ultrasonic surface waves

This method uses the ultrasonic waves with different polarisation directions, travelling along the axial direction. It uses the reflectivity at the interfaces as the observable and offers the possibility to inspect large areas. The main focus lies on the detection of imperfections in the adhesive layer and of delaminations.

Instrumental:
- The choice/development of suitable transducers on EMAT basis (wave mode, polarisation direction).
- Adaptation of the inspection mechanics to the requirements of ultrasonic surface testing.

Ultrasonic inspection of bonded plates and pipes in dependence on:
- Wall thickness of the adherents.
- Adhesive.
- Adhesive layer thickness.
- Surface state and surface preparation.
- Artificial defects in the adhesive layer interfaces.
- Wavelength (frequency) of generated ultrasound.

Laboratory: Thermography and vibration techniques

Thermography is used to inspect the curing procedure of large area bonds. Here the temperature development during the process as well as external excitation (electrical, microwave, light, vibration) can be used. Low frequency vibration methods have a certain potential to detect disbonds in adhesively bonded joints. Those techniques in principal detect local variations in stiffness of a bonded structure (mechanical impedance method) as a consequence of a good and defective area.

All the described techniques will be evaluated. Comparing the results of the different studies and techniques, a decision has to be made which method or combination of methods will be suitable for the application in the field. SZMF will be in charge of this part of the project (Task 2.1).

Task 2.2 Development of a repair procedure

In case a defect has been detected, it has to be decided whether it is tolerable or has to be repaired. In this case a procedure has to be worked out, how a fast and reliable repair can be performed and how eventually the adhesive pipe joint can be separated again. As a basis for the decision, the NDT-methods have to exhibit quantities (i.e. amplitudes, thresholds) determined by the studies on artificial and natural defects, which give a clear and reliable indication of where and how a repair has to be performed.

SZMF will do the work on the development of a repair procedure in the laboratory. The repair procedure will be evaluated mechanically in the next work package (WP3) with destructive tests and from a logistical point of view in WP4 where a practical pipe laying test will be performed. The work on this task will be done by SZMF with main consultancy of SIKA. The necessary full scale pipes will be supplied by MFR.

Task 2.3 Transfer of the technologies to field conditions

All the above mentioned procedures have to consider the situation in the field, which gives limitations to:

- Handling of the pipes.
- Handling of the NDT equipment.
- Education of the inspection people.
- Environmental influences (dirt, water, humidity etc.).
- Spare time for the inspection.

A concept has to be developed, how the methods can be applied to full sized pipes, taking into account:

- The inspection of the whole bonded area without any gaps. This comprises a concept for a robust and field suitable mechanical set-up.
- The application of sensors and transducers: In case of piezo transducers, the question has to be answered how the coupling medium can be applied to the specimen.
- How the results are presented to the inspection engineer (user interface).

The work on this task will be done by SZMF with support of UPB and under consultancy of the pipe laying industry (B&D) and the end users (Gaz de France). All full scale pipes which are necessary for the examinations will be supplied by MFR, (only short parts of pipes are necessary in this work package.)

3 - Interrelation with other work packages

This work package needs the results coming from WP1. WP2 will not only use the preliminary concept worked out in WP1 on small specimens tests, furthermore it is worth noting that the survey of main requirements for pipe joints in the field and in-service loading conditions (Task 1.1) is essential in order to preselect adequate non-destructive-testing methods and repair methods that are capable to meet the requirements on the construction site. Although, the development of the in-process quality control concept (Task 2.1) can already start right after the survey of the requirements (Task 1.1) as the project team already developed joint geometries for both small and large steel pipes as part of the preparation stage for this proposal. This guarantees a smooth work progress of this project also in case of delay of WP1.

Both the repair method and the non-destructive-testing technique will be verified on a practical pipe laying test in the field which will be performed in WP4. Furthermore, joints with defect for full scale testing in WP3 will be selected and prepared. The results of these tests will have influence on the valuation of the inspection results.

4 - Deliverables and milestones

The aim of work package WP2 is the development of a detailed inspection procedure and the concept for a time and cost saving application method in the field. Therefore, the deliverables will be an evaluation of different inspection procedures in terms of its use for adhesively bonded steel pipe joints. At the end of this work package a suitable non-destructive-testing procedure for adhesive steel pipe joints will be available as well as a reliable repair method for the application in the field.

ANNEX I
Form 1-2
OBLIGATORY AT THE SUBMISSION STAGE

WORK PACKAGE DESCRIPTION	**WP No**	**3**

Work package Title	Full scale testing of adhesively bonded pipe joints	**Number of man hours**[29]
WP Leader	Centro Sviluppo Materiali S.p.A. (CSM)	4380
Contractor	Mannesmann Fuchs Rohr GmbH (MFR)	300
Contractor	Arbeitsgemeinschaft für Wärme und Heizkraftwirtschaft e.V. (AGFW)	10
Contractor	University of Paderborn (UPB)	1500
Contractor	Salzgitter Mannesmann Forschung GmbH (SZMF)	1850
Contractor	Gaz de France (GdF)	10
Contractor	Sika Danmark (SIKA)	20
Total		**8070**

1 – Objectives

The main objectives of this work package are the following:

- Definition mechanical properties (stress strain design curves) based on a dedicated test program on full scale pipes.
- Save defect tolerance criteria based on a dedicated test program on full scale pipes.
- FEM simulation concept for adhesive pipe joints.

2 - Work programme and distribution of tasks with indication of participating contractors

Task 3.1: Definition mechanical properties (stress strain design curves)

In industrial environment, only limited time is available for the design phase of pipe lines or other constructions. The most efficient material laws from a user point of view are undoubtedly based on tabulated stress-strain curves obtained directly from physical testing. Useful data is necessarily based on experimental material testing.

The general aim of this work package is the definition of mechanical properties and the evaluation of in-service performance of adhesively bonded steel joints in order to derive a criterion for stress/strain design of pipeline made using adhesively bonded joints. To achieve this goal a dedicated test program will be set up and performed in collaboration with both the adhesive industry and the pipeline industry.

The test program will be subdivided in two phases: laboratory tests on small parts of pipe joints and full-scale tests performed on a limited numbers of selected joints. The tests performed on small-scale pipe joints will be executed by SZMF. In parallel, a dedicated full-scale test program will be performed, first, in order to verify the findings made on small-scale specimens and, second, to finally validate the new joint design concept under realistic service conditions. In detail, the full-scale test program will comprise the items listed below:

- Static tensile tests (positive axial force) …(SZMF)
- Static bending tests …(CSM)
- Static torsion tests …(SZMF)
- Static pressure containment tests …(SZMF)
- Alternating tensile/compression tests (positive/negative axial force) …(SZMF)
- Cyclic pressure containment tests …(SZMF)
- Multi-axial testing 1: pressure containment + positive/negative axial force (static and cyclic) …(SZMF)
- Multi-axial testing 2: pressure containment + bending moment …(CSM)
- Multi-axial testing 3: pressure containment + torsion …(SZMF)
- Evaluation of resistance against denting and puncture simulating dynamic external threats such as impact due to mechanical equipment like excavators …(CSM)

In the above tests, loads and displacements shall be recorded continuously during testing, notably in axial direction directly at the interface between joint and out-bounding pipe. Prototype testing shall neither lead to any form of burst failure nor de-bonding nor leakage.

The full scale test program will be done in joint co-operation of CSM and SZMF, both parties having extensive expertise in this field. CSM can perform its part of the test program making use of existing dedicated facilities like an excavator simulator (suitable for any type of diameter and a maximum length of about 5 m) and readily available equipment for simulating interaction of internal/external pressure and bending loads. Likewise, SZMF is capable of performing its part of the test program independently utilizing approved testing facilities.

The full scale test program in Task 3.1 will be done on selected types of joints (maximum 3 geometries). MFR (Mannesmann Fuchs Rohr) is in charge for the supply of these pipes.

Task 3.2: Save defect tolerance criteria

The above indicated full scale test program will not only be performed on selected kinds of received joints, moreover it is planned to also perform these tests on joints with "defect" and joints damaged by environment and cyclic loads. About this last, a realistic load/environments laboratory cyclic to reproduce the potential in service damage will be fixed under consultancy of pipe laying industry (B&D) and end users (Gaz de France). The experimental tests will be done by CSM. UPB will work out the defect tolerance criteria based on the experimental test data (CSM).
MFR (Mannesmann Fuchs Rohr) is in charge for the supply of the pipes. All joints will be made and inspected by SZMF using the methods developed already in the previous work package WP2.

Task 3.3: FEM simulation concept for adhesive pipe joints

Simulation with the Finite Element Method is state-of-the-art today. Simulation is important to verify construction concepts and to shorten the time used for the design phase.
The aim of this task is to develop a suitable Finite Element calculation concept to simulate adhesive pipe joints. Furthermore, these simulation tools should have the capability to predict the long-term stability of the joint. The result will help design engineers to optimise new pipe joint geometries. The FE-concept has to take into account not only the mechanical forces, such as axial loads. Moreover, the properties of the used adhesives under different mediums and temperature have to be modelled. The FE-concept will be worked out by UPB and will be verified by the full scale tests done in this WP. It has to be mentioned that UPB has a great expertise and long-term experience in modelling adhesively bonded joints since UPB is working on the development of FE-calculation concepts together with adhesive industries and end users since many years. It is worth saying that the FE-calculation concept for adhesive bonded pipe joints can be based on the experience and knowledge gained in terms of modelling of adhesive joints in the automotive industry where adhesive bonding is already a key technology. The UPB is working on this research field with the automotive industry since many years.

3 - Interrelation with other work packages (please give WP No)

For the successful competition of this work package the WP1 and WP2 are important and their conclusions are needed. For instance: the joints with "defect" that are tested in Task 3.2 of this WP will be inspected by the non-destructive-testing methods developed in Task 3.1 of the previous WP. The knowledge gained in this WP will be used in WP4 in order to derivate guidelines and a easy-to-use design method for adhesively bonded pipe joints in the gas, water or heat distributing net.

4 - Deliverables and milestones

At the end of this work package a dedicated know-how about the design and inspection of adhesive pipe joints will be available. The stress strain design curves together with a save tolerance criteria as well as a Finite Element calculation concept are main deliverables. This experimental data is obtained under a variety of different loads, typical for the wide range of different load conditions in the gas, water and heat supply industry. A realistic FE-model for adhesively bonded pipes is another important step in order to introduce the developments of adhesive bonding technology of recent years into pipe laying industry.

ANNEX I
Form 1-2
OBLIGATORY AT THE SUBMISSION STAGE

WORK PACKAGE DESCRIPTION	**WP No**	**4**

Work package Title	Verification of consistent adhesive bonding concept under field conditions	**Number of man hours**[29]
WP Leader	Bohlen & Doyen Polska Sp. Z o.o. (B&D)	1870
Contractor	Centro Sviluppo Materiali S.p.A. (CSM)	10
Contractor	Mannesmann Fuchs Rohr GmbH (MFR)	400
Contractor	Arbeitsgemeinschaft für Wärme und Heizkraftwirtschaft e.V. (AGFW)	30
Contractor	University of Paderborn (UPB)	2460
Contractor	Salzgitter Mannesmann Forschung GmbH (SZMF)	40
Contractor	Gaz de France (GdF)	40
Contractor	Sika Danmark A/S (SIKA)	50
Total		**4900**

1 – Objectives

- Practical pipe laying test at construction site in order to verify the developed adhesive bonding concept under field condition and in order to assess developed adhesive bonding concept against conventional joining techniques
- Detailed cost calculation to compare this new bonding technology for steel pipes with conventional joining techniques.
- Fixing practical guidelines/recommendations and design calculation methods for adhesive bonding of pipes in the gas, water and heat distribution net.

2 - Work programme and distribution of tasks with indication of participating contractors

Task 4.1: Practical pipe laying test at construction site in order to verify the developed adhesive bonding concept under field condition and in order to assess developed adhesive bonding concept against conventional joining techniques

WP4 is scheduled after the first three work packages where a consistent adhesive bonding concept for steel pipes has been elaborated and evaluated with small scale specimens (WP1) over full scale non-destructive-tests (WP2) up to full scale destructive tests and FE-calculations (WP3). Finally, the developed bonding concept will be verified on a practical field lay test at the construction site under field conditions (WP4). The practical pipe laying tests is important because it reveals logistical and technical advantages and disadvantages of the new bonding concept.

The lay test will be done by the pipe-lying company Bohlen & Doyen Polska Sp. Z o.o. (B&D) which have more than 50 years experience in pipe constructions. Mannesmann Fuchs Rohr GmbH (MFR) will supply B&D with the pipes for the pipe laying test at the construction site. The field tests will be done under consultancy of Gaz de France.

Task 4.2: Detailed cost calculation to compare this new bonding technology for steel pipes with conventional joining techniques.

In order show the progressiveness of the developed adhesive bonding concept an assessment of this concept against conventional joining techniques (welding, mechanical fastening) will be performed by UPB based on an analyse of the field tests. This includes a detailed cost calculation done by UPB under consultancy of both B&D and Gaz de France in order to compare the developed new concept with conventional joining techniques. This comparison has to cover not only the costs for the bonding process itself but also for all parts and technical devices necessary for a long term use of the pipeline. Therefore, also present pipeline requirements for operation and maintenance processes such as piggability and CP for underground lines have to be taken into account.

Task 4.3: Defining practical guidelines/recommendations and design calculation methods for adhesive bonding of pipes in the gas, water and heat distribution net

Together with the background of knowledge gained in the first three work packages the evaluation of the practical pipe lying test will be the foundation to derivate practical guidelines for an easy-to-use bonding concept at the construction site. This work will be done by UPB under participation of B&D and Gaz de France. The work in this task will be supported by AGFW. AGFW which is an umbrella organisation ensures an optimal exchange of experience prepares technical standards (“AGFW work sheets”) with requirements and test procedures also as instructions for the use of the technical solutions. New standards will be worked out with all groups concerned (manufacturer, suppliers, test laboratories and others). Before a new standard coming into force the whole branch of industry has the possibility to give their statements to the published working documents.

3 - Interrelation with other work packages (please give WP No)

This WP will take into account all previous work packages with their analysed results.

4 - Deliverables and milestones

The deliverable of this work package is the presentation of an innovative bonding concept using the pace developments of adhesive bonding in recent years. Furthermore, practical guidelines for adhesive bonding of pipelines will be supplied. Furthermore, a detailed cost calculation will be worked out under consultancy of Gaz de France. This evaluation covers not only costs for the bonding process itself but also for all devices and technical requirements necessary for a long term use of the pipeline. The costs will be compared with the costs for conventional pipe joints.

ANNEX I
Form 1-2
OBLIGATORY AT THE SUBMISSION STAGE

WORK PACKAGE DESCRIPTION	**WP No**	**5**

Work package Title	Management and co-ordination of the project	**Number of man hours**[29]
WP Leader	University of Paderborn (UPB)	950
Total		**950**

1 – Objectives

- Management and co-ordinations of the project and maintaining adequate lines of communication between all partners in order to achieve the project objectives within the time and budget allocated.
- Preparation of the output of the project including the final report.

2 - Work programme and distribution of tasks with indication of participating contractors

5.1 Management and co-ordinations of the project

Fig. 7 shows the management structure of the project.

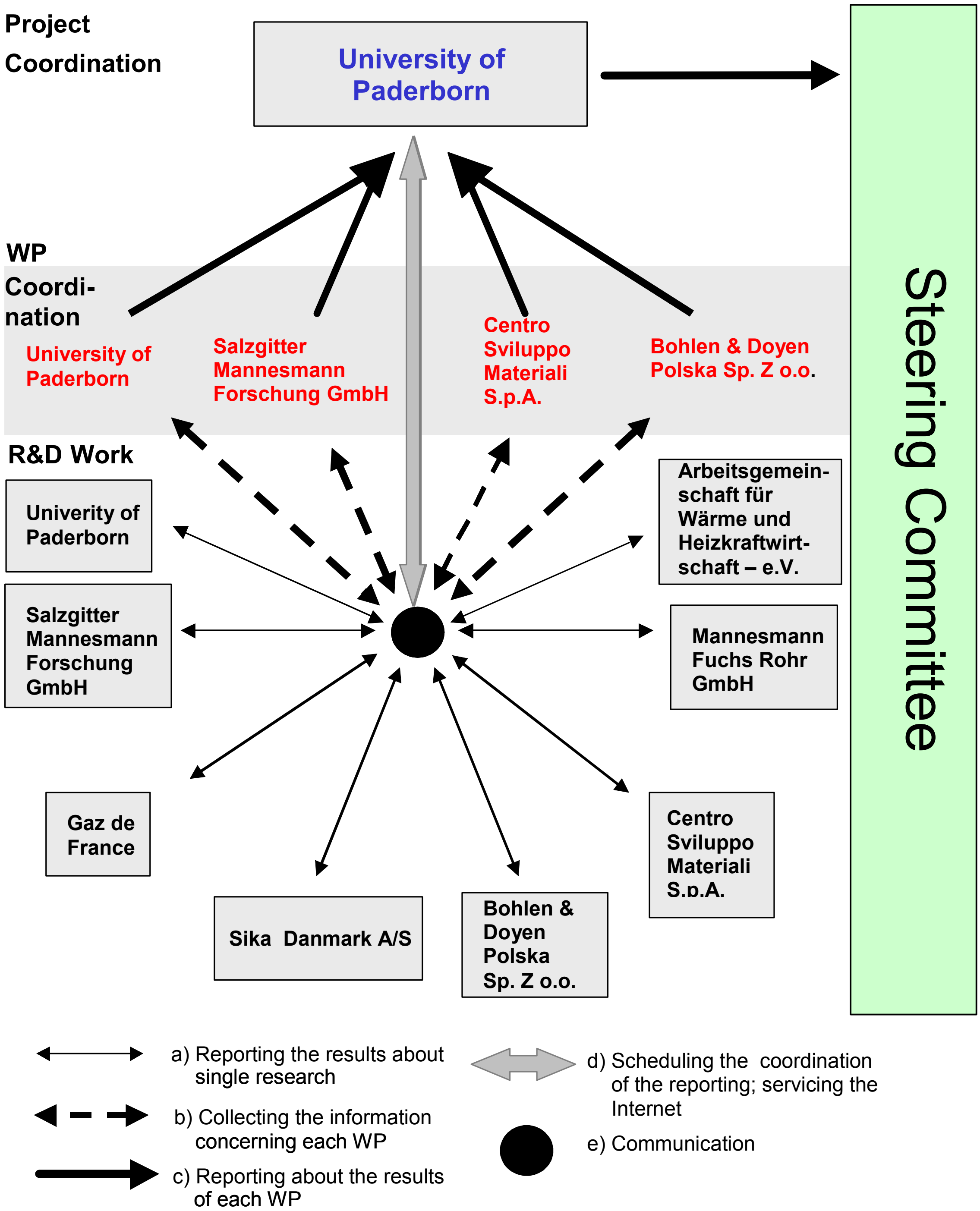

Fig. 7: Management Structure.

5.1 Management and co-ordinations of the project (cont´d)

The project coordinator (UPB) manages the research programme including the financial coordination. Progress will be monitored against the project plans by comparing resources consumed and the technical progress made with the costs and objectives planned in each sub-work package. This will be done twice a year on the occasion of the project meetings to be held in which each coordinator of a sub-work package presents a progress report. Progress reports will summarise technical progress and project expenditure every three months, identify to what extent progress and expenditures are in line, identify any technical difficulties or circumstances likely to affect progress and outline planned activities for next reporting period. The work of each work package will be accompanied and monitored by the Coordinator (UPB). In this way any difficulties can be identified and dealt with when they arise. These reports will be assimilated by the project coordinator and used to compare with the scheduled programme and resource allocation.
Decisions will be made concerning future direction of each partner and action will be taken to rectify any activities where progress is not in line with the programme. The work of each work package will be accompanied and monitored by the Coordinator (UPB).
A steering committee which will by formed by Prof. Dr. Hahn (UPB), Prof. Dr. Niemeyer (SZMF) and Dr. Demofonti (CSM) will meet in the case of major problems during the research work.

The Laboratory of Materials and Joining Technologies (LWF) which is a department of the University of Paderborn (UPB) will actually execute the work on this research project. LWF has a long experience in coordination and development of research projects in the field of joining techniques The LWF allocates resources and qualified staff for management of the project. Furthermore, the co-ordinator Dipl.-Ing. Wissling (LWF), in particular, brings in also practical experiences from the pipe laying industry since he worked as an engineer on several international pipe laying projects. Before he started his research career at the LWF, Mr. Wissling worked in the Netherlands and the USA for Heerema Marine Contractors (HMC) which is a Dutch company that provides design, transportation and installation services to the international oil and gas industry.

The Europe Liaison Office at the University of Paderborn consults the UPB as the project coordinator in special questions of administrative affairs in order to guarantee an optimal financial coordination and optimal project process. As the Europe Liaison Office is part of the University of Paderborn collaboration is easily possible.

As coordinator his responsibilities for the Consortium and towards the Commission are:

- Collect all reports and documents submitted to the Commission or other participants.
- Collect progress reports.
- Send all cost statements and consortium agreements.
- Ensure prompt payment of financial contributions.
- Verify timetable in the way that milestones are met.
- Review project progress in the way that economic and technical objectives and targets are met.
- Solve possible problems arising from administrative, contractual or partnership issues
- Organisation of meetings.
- Provision of meeting minutes and follows up of agreed actions.

The progress monitoring may require coordinator visits to different partners when major task is executed (large scale testing on pipes) or prior to milestones of key deliverables.

5.1 Management and co-ordinations of the project (cont´d)

Communication structure:
Internet based project centre will be launched for collecting reports and related information. This centre will be linked to e-mail which notifies added documents and reports. Proactive frequent informal communication between participants is encouraged vial e-mail.
Next to the normal meetings additional conferences may be called when urgent problems arise and solving of them is needed. In order to save time and travelling resources, some of those meetings will be held via e-mail ballot and confirming conference call or internet-assisted meeting when all partners may discuss and select one of their screens to watch (e-meeting). In addition to official meetings, the facilities can be used within technical discussions with smaller number of participants.

5.2 Preparation of the output of the project

Every month the WP leader will assess and report on the progress of task in his WP. Possible deviations from the detailed project plan will be reported. Proposals for corrective action to ensure that key deliverables and milestones are met. Every six months progress report will be circulated that contains summary of all work carried out in the previous six-month period.

After 18 months, a report which covers the whole first period of the project will be prepared. The expenditure of funding is included and comparison to allocation in the budget is done by each participant. This report is also mid term review of the project, where critical examination of results available is done reflecting the resources and allocated costs.

3 – Interrelation with other work packages

WP1-WP4: management and co-ordination of the project

4 - Deliverables and milestones

Progress reports, progress meetings, final report, etc.

EUROPEAN COMMISSION
RESEARCH DIRECTORATE-GENERAL

Directorate G – Industrial Technologies
Research Fund for Coal and Steel

ANNEX I
Form 1-3
OBLIGATORY AT THE SUBMISSION STAGE

PROGRAMME BAR CHART (TASK, PARTNER, DELIVERABLES, MILESTONES)

Work packages	*Work packages title*	*Deliverables*	**Hours on project/ Contractor(s)**								**1st year**				**2nd year**				**3rd year**			
			1	2	3	4	5	6	7	8	I	II	III	IV	I	II	III	IV	I	II	III	IV
WP 1	**Joining Fundamentals**		**3460**	**205**	**10**	**750**	**100**	**10**	**10**	**30**												
Task 1.1	Survey of requirements	Working points	100	50	10	20	50	10	10	10	🟩	🟩										
Task 1.2	Optimisation joint design	Joint geometry	200	50		50					🟩											
Task 1.3	Development adhesive	Adeq. adhesive	1100			450					🟩	🟩										
Task 1.4	Selectio. surface treatment	Surfa. treatment	900			100	25			10	🟩	🟩	🟩	🟩								
Task 1.5	Devel. application method	Opt. applic. met	1160	105		130	25			10		🟩	🟩	🟩	🟩							
WP 2	**Process Quality Control**		**200**	**1900**	**20**	**30**	**80**		**200**	**10**												
Task 2.1	Quality control system	Control system		900			10		100			🟩	🟩	🟩								
Task 2.2	Repair procedure	Repair proced.		800		30	10		50				🟩	🟩	🟩	🟩						
Task 2.3	Transfer t. field conditions	Suitability	200	200	20		60		50	10			🟩	🟩	🟩	🟩						
WP 3	**Full scale testing**		**1500**	**1850**	**10**	**20**		**4380**	**300**	**10**												
Task 3.1	Full scale tests	Stress strain cur	350	1700				2080	250						🟩	🟩	🟩	🟩				
Task 3.2	Defect tolerance criteria	Tolerance crit.	350	150	10			2000	50	10							🟩	🟩	🟩			
Task 3.2	FEM-model	Calc. model	800			20		300			🟩	🟩								🟩		
WP 4	**Adhesive bonding concept**		**2460**	**40**	**40**	**50**	**1870**	**10**	**390**	**30**												
Task 4.1	Pipe laying test at site	verification	300	20	30		1200		300	10							🟩	🟩	🟩	🟩		
Task 4.2	Comparison with welding	Cost calculation	1500	20	10	40	500		50								🟩	🟩	🟩	🟩		
Task 4.3	Guidelines, design criteria	Design criteria	660			10	170	10	40	20									🟩	🟩	🟩	🟩
WP 5	**Co-ordination**		**950**																			
Task 5.1	Co-ordination	Teamwork	500								🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Task 5.2	Reports	Reports	450									🟩		🟩		🟩		🟩		🟩		🟩
Total Hours on project			**8570**	**3995**	**80**	**850**	**2050**	**4400**	**900**	**80**												