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Exhibit No. ____

Worldwide Court Reporters, Inc.

In re: Oil Spill by the Oil Rig "Deepwater Horizon" in the Gulf of Mexico, on April 20, 2010

UNITED STATES DISTRICT COURT

EASTERN DISTRICT OF LOUISIANA

MDL NO. 2179, SECTION J

JUDGE BARBIER; MAGISTRATE JUDGE SHUSHAN

Expert Report of Andreas Momber

EROSION OF WELL-CEMENT DUE TO HYDROCARBON FLOW

May 1, 2013

CONFIDENTIAL

Executive Summary

The evidence suggests that before the Macondo incident the bottom of the wellbore was filled with cement; cement filled much of the casing up to the float collar, and more cement filled part of the annulus around the lower portion of production casing. At the start of the blowout, this column of 189 feet of cement in the bottomhole would have impeded the flow of oil dramatically. As flow continued over time, this cement would have been degraded through multiple processes, including cement erosion. This in turn would have permitting ever increasing amounts of oil to flow into the well. It is thus critical to understand how fast these bottomhole degradation processes likely happened. The United States' expert reports ignore or misjudge the importance of cement erosion and other degradation processes. The few reports that discuss cement erosion simply assume that all of the bottomhole cement was essentially completely and almost immediately eliminated within a very short time after the blowout (taking only 9 hours to 2 days). In my opinion, this type of rapid and complete erosion of well cement is inconsistent with what is known about the cement erosional processes. In fact, for the government experts' assumptions to be true, it would require one to believe that erosion rates at Macondo were many times greater than the highest reported rates for the erosion of cement mixtures.

I conclude, based on my experience working in the field of cement erosion, that instead, the well cement likely underwent a *4-step degradation scenario*, which I explain below. Under this scenario, a different process, known as hydraulic fragmentation, caused the rapid initial degradation of a portion of the cement in the casing. But this fragmentation process would be limited mostly to the formation of a net of cracks and fractures. This period was followed by an erosive process during which the flow paths in the cement gradually became wider. This is consistent with available data and my experience with how cement degrades under high pressure flow.

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1 Expertise

My consulting, research, and teaching career has focused on erosion processes, particularly of mineral-based materials such as cement. During my over 20 years in this field, I have studied erosion due to liquid flow, slurry flow, cavitating flow, and droplet flow. I also did research in other degradation processes, namely fragmentation and contact damages. Results of my investigations are published in more than 80 papers in high-level peer-reviewed journals, and the work was cited about 700 times in the reference literature according to the Google Scholar Index. I serve as a peer reviewer on a regular basis to numerous scientific journals and associations. I also am the author of various books on erosion related topics, including a book dedicated to studying the hydrodemolition of concrete surfaces. My research interests include contact mechanics, fracture mechanics and surface engineering. I am a lecturer at the Department of Geo-Resources and Materials Technology at the Aachen University of Technology in Germany in the field of erosion of geomaterials. I have been involved in scientific research programmes in Australia, Germany, Great Britain and the United States and served to a number of universities as a Visiting Professor/Lecturer.

2 Introduction

The United States' expert reports do not contain a proper analysis of the impact of cement degradation processes (including erosion) on the probable flow rate and total flow volume. The few experts that do mention cement erosion do so in a conclusory fashion and do not discuss (or apparently consider) the principles of cement erosion. Contrary to their assertions, it is scientifically unsound to assume that the cement would have completely eroded within hours or a few days. I conclude that it is more likely that the cement at the bottom of the well underwent a *4-step degradation scenario*, which would have included a period of rapid non-erosional degradation process followed by periods of much slower erosion.

To understand why the United States' experts are wrong when they simply assert that cement erosion would have been complete in hours or few days, it is necessary to understand cement erosion. I turn to that next.

2.1 Background on erosion

Erosion of cement-based materials is a common phenomenon in engineering, and it occurs particularly if there is high-speed liquid flow (such as water or oil) through paths in the cement. The existence of solid particles in the liquid flow (called a slurry) will notably increase the severity of erosion.

Others have concluded that the oil passed through the well cement barrier between the shoe and float collar, as illustrated in *Figs. 2.1* and 2.2. Consequently, a flow path must have been formed in the well cement allowing the oil to flow into and up the shoe track. The question becomes whether erosion could have formed such a path. I note that this report addresses only the possible flow path in the well cement and focuses on how that path may have changed after the blow out.

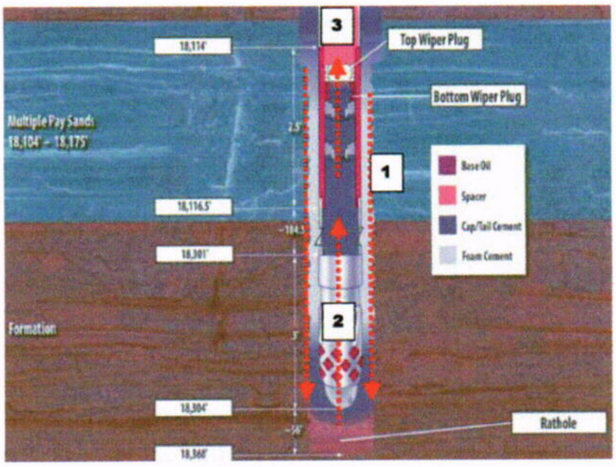

Figure 2.1
Shoe track hydrocarbon penetration path.[1]

[1] *Final Report on the Investigation of the Macondo Well Blowout.* Deepwater Horizon Study Group, March 1, 2011.

Understanding erosion (and other potential processes I discuss) is a crucial aspect of understanding the cement flow path and how it might have changed over time, because erosion will notably affect the flow rate of the oil. This is intuitive: the amount of resistance/restriction in the bottomhole impacts the amount of oil that can flow into the well--for example, the size of the opening in the cement (such as channels) can impact the amount of oil that flows into the well.

Nevertheless, the government experts have not developed a thorough approach to investigate the effects of erosion of the well cement, as I will discuss next.

2.2 Consideration of cement erosion in the United States' Expert Reports

Cement erosion is briefly mentioned in the reports of Griffiths and Dykhuizen, but both experts make unfounded assumptions regarding the amount and rate of erosion. The Griffiths Expert Report claims that "*significant erosion of the ... cement barrier in the bottom of the well occurred rapidly over the first few days following blowout. Subsequent erosion had little impact on flow rates or on the cumulative discharge.*" [2] Yet he acknowledged that "*the methodology I used cannot address ... erosion directly.*" [3]

Dykhuizen wrote that "*I do not believe that erosion had a significant effect on overall flow from the well past the second day of the blowout.*"[4] Neither offers any convincing proof to support their assertions.

Thus, although these experts accept erosion of several parts of the flow path for the first few days after the blowout, they ignore it for later periods. These experts attempt to justify this by suggesting that such a position follows from undisclosed "*simple models*." Griffiths, looking at Emilsen's work in BP's *Deepwater Horizon Accident Investigation Report*, admits that there was some sort of blockage downhole at the beginning of the incident.[5] Griffiths contends that Emilsen's work showed an increase in net pay from zero to between 13 and 16.5 feet over a 30 minute period (from 21:00 and

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[2] Griffiths Report , 4 (2013).
[3] *Id.*
[4] Dykhuizen Report, 11 (2013).
[5] Griffiths Report at 11.

21:30).[6] He then concludes that, based on this alleged rate of change to the net pay, downhole restrictions would have eroded in 9 hours (actually 8.6 hours). I do not draw such conclusions from Emilsen's work, but I accept Griffiths's assertions solely for purposes of this report.

Dykhuizen and Griffiths make important assertions, which should be supported by rigorous analyses. Based on my experience and the scientific literature concerning cement erosion, I find the erosion rates being posited by the government experts to be implausible.

To understand that, we must first understand how much cement was likely at the bottom of the well.

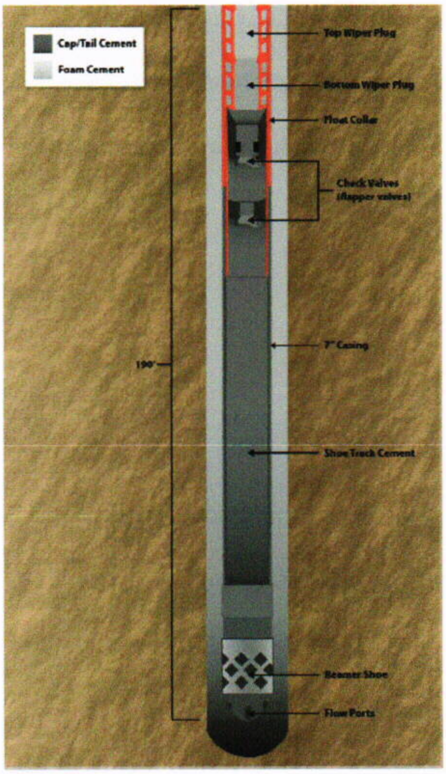

Figure 2.2
Schematic of the cement-filled shoe track.[7]

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[6] *See id.* at 11 (noting also that the productivity index used in his model increased by over 25% during this period and attributing this rise to Emilsen's observations).

[7] Source material for this schematic is the BP Accident Investigation Report (the "Bly Report").

3 Location and amount of well cement

3.1 Location

The cement barrier in question is located between the shoe and float collar, as illustrated in *Figs. 2.1* and *2.2*. It has the geometry of a column that can be characterized by its height (h_C) and its diameter (D_C). Indeed, this is a conservative assumption, because cement also filled part of the annulus and would have provided a barrier to flow there as well.

3.2 Volume of well cement

The *Halliburton Post Job Report* states that there is 189 feet of cement in the shoe track.[8] The volume to be eroded (V_C) is simply the volume of cement in the cylindrical casing and is given as follows:

$$V_C = \frac{\pi \cdot D_C^2}{4} \cdot h_C \tag{3.1}$$

The internal diameter of the 7-inch-pipe (the production casing) is 6.094 inches.[9] If we take this as the diameter of the cement column (D_C=6.094 inch) and h_C=189 ft (57 m), then the volume of cement (V_C) in the column is approximately 38 ft^3. In other words, there was 38 cubic feet (around 7 barrels) of cement located in the Macondo's shoe track.

4 The conditions at Macondo may have allowed for channelling in the cement

The conditions of the cement in the shoe track and annulus are not known with certainty. But the fact that others have concluded that oil flowed up the casing suggests that the cement structure was disturbed.

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[8] BP-HZN-2179MDL00154146.
[9] Bly Report, Appendix W, Table 1.3.

4.1 Flow channels

The existence of flow channels in deteriorated cement is an established phenomenon in well systems. Some examples of flow channels that can form in deteriorated well cement are provided in *Table 4.1*. Pre-existing flow channels can be subdivided into three general types (see *Table 4.1*):

- an individual, comparatively large flow channel (situation 5 in *Table 4.1*);
- a number of parallel capillaries (situation 3 in *Table 4.1*);
- a net of cracks, pores and flaws (combination of situation 3 and 6 in *Table 4.1*).

The existence of pre-existing flow channels cannot be neglected in flow-condition and erosion analyses. These flow channels will alter the structure of the cement material, and they can act as pathways for penetrating fluids. The following two examples may illustrate these effects:

- Cracks as small as 500 µm (millionths of a meter) in a cement-based composite can increase the permeability of the material by some orders of magnitude;[10]
- Foam-type pores in concrete can increase its permeability by a factor of 10.[11]

4.2 Potential for formation of pre-existing channels in the Macondo well

The conditions for the formation of channels may have been present at Macondo. This would include the following possibilities[12]:

- contamination of the cement by nitrogen breakout and migration from nitrified foam cement;
- inadequate design of the cement;
- inadequate testing of the cement.

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[10] *Lepech and Li, 2005.*
[11] *Sanjaya et al., 2007.*
[12] Bly Report, at 34.

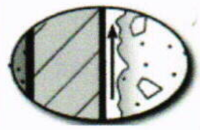
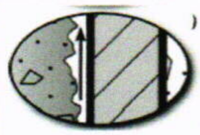
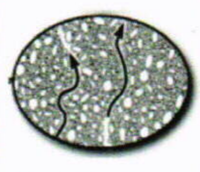
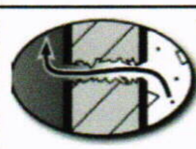
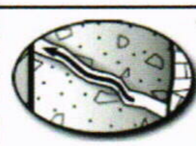
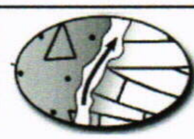
Situation		Image	Importance
1	Between cement and casing		Contact stresses; interface shrinkage; deteriorated bond
2	Between cement and casing		Contact stresses; interface shrinkage; deteriorated bond
3	Through the cement		Insufficient mixing; unfinished hydration; pore system; high permeability; degradation
4	Through the casing		Casing erosion (solid particle/slurry erosion)
5	Through fractures in cement		Cracked cement
6	Between cement and formation		Contact stresses cement/ rock, developed during cement slurry setting

Table 4.1: Possible flow paths in a deteriorated well; note situations 3 and 5[13]

Accordingly, it is quite reasonable to assume that the well cement had one or more channels in it by the time of the blowout.

5 Evidence for pre-existing flow channels and cement degradation

5.1 Emilsen's analysis suggests that there was some cement blocking the reservoir.

Emilsen modeled events leading up to and including the blowout. The 200-psi pressure increase recorded at 21:08 on the night of April 20, 2010, was modeled by Emilsen by assuming hydrocarbon flow through the production casing shoe and through the well cement.[14] This phenomenon could be

[13] Adapted from *Celia*, 2010. I added the right column.
[14] Bly Report, Appendix W, at viii.

explained by assuming the existence of initially small channels in the cement between reservoir and wellbore.[15]

The instantaneous flow rates for Emilsen's best model match are reproduced in *Figure 5.1* below.[16] In this model, the flow rate gradually increased until just before 21:30; the flow rate then increased more rapidly. Griffiths asserts that this shows a fast erosive process.[17] I agree that it is instructive to assume that this change in model flow rate is related to the capability of the cement material to resist oil flow. The sudden change in flow rate around 21:30 may reflect a notable drop in the cement's resistance to flow. In other words, around 21:30, the cement began to permit more hydrocarbons to flow through it. Contrary to the assumption of the United States' experts, erosional processes cannot explain this short-time event. Other mechanisms must be considered at play.

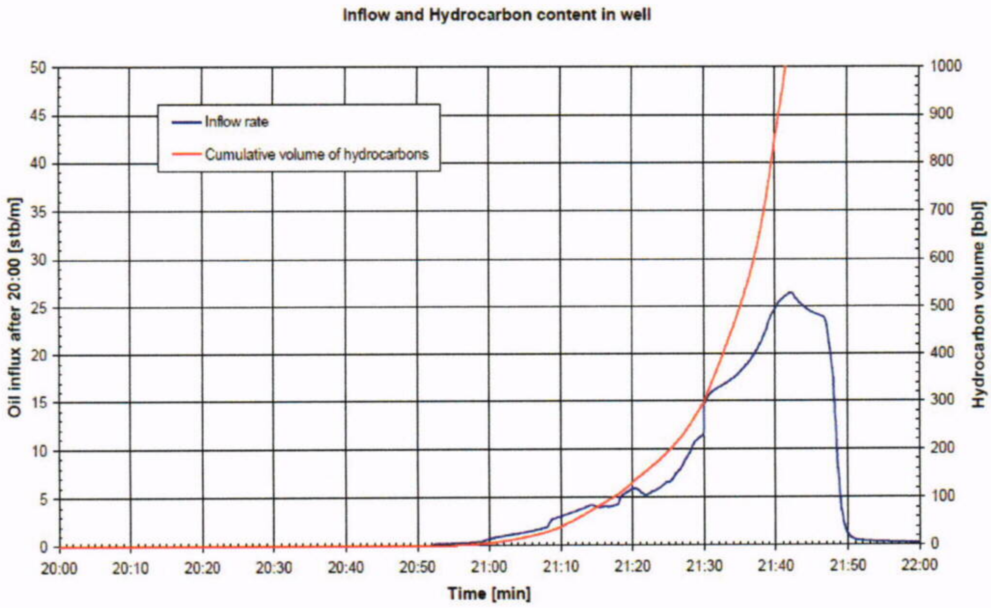


Figure 5.1: Emilsen's simulation that most closely matched witnessed events and recorded data. It shows a varying oil influx rate over time.[18]

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[15] *Id.* at 54 (noting that it is possible that there were initially small channels in the cement and that more of the reservoir became exposed as drawdown increased).

[16] *Id.* at 55.

[17] *See* Griffiths Report, page 11, n. 10.

[18] Bly Report, Appendix W, page 55.

Emilsen concluded that his best model match is for a net pay of between 13 feet to 16.5 feet, and that flow was through the casing shoe and up into the rest of the production casing. This tells us that there was some blockage of the reservoir oil. A reasonable inference from this is that there was substantial cement impeding flow in the wellbore, but that flow was occurring through channels in the cement.[19]

Griffiths argues that if there was cement at the bottom of the well, "*the likely mechanism for progressive failure is erosion*" where the rate of failure would be caused by the opening of "*small channels*" in the cement.[20] He calculates the erosion period to be less than 9 hours before the cement and other impediments would no longer provide significant restrictions to flow from the reservoir into the casing.

To evaluate Griffiths' assertions regarding the rate of erosion, I will next consider the possible flow paths in the cement.

5.2 Estimate of flow path dimensions

The size of the flow path, particularly the cross-sectional area, must take into account flow rate and pressure drops. The flow path cross-section must allow the flow rates shown in *Figure 5.1*, namely the highest flow rate of around 27 stb/min, but it must also be narrow enough to have the corresponding resistance to the flow and pressure drop. We can estimate the diameter of the cement channel before and after the increase in flow rate around 21:30 reflected in the model. As is shown in the Appendix A, for a flow rate of 12 stb/min, based on a net pay of 13 feet, we expect a pressure drop of 1980 psi across the cement channel. This correlates to a flow diameter (d_F) of 2.17 inches. And for a flow rate of 27 stb/min, we expect a pressure drop of 3496 psi across the cement channel based on a net pay of 16.5 feet. This correlates to a flow diameter of 2.64 inches.

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[19] Bly Report, Appendix W, page vii ("It is probable that the sands were restricted to some degree by the cement and downhole equipment and that the resulting reservoir exposure is less than the total reservoir thickness.").

[20] Griffiths Report, page 12, n. 11.

These results can be converted into percentages of the cross-section of the long cement column covered by flow path. For the lower flow rate, we obtain: $(2.17/6.09)^2=0.13$ (13%). For the higher flow rate, we obtain: $(2.64/6.09)^2=0.19$ (19%). That would mean that between 13% and 19% of the cement column might be open to flow. Note, however, that the cement column would still provide a sizable flow restriction as evidenced by the large pressure drop across it of between 2000 and 3500 psi. (Flow restrictions cause pressure drops.)

6 Erosion rate considerations

6.1 Eroded volume

One can assume that the total volume of cement in the well column needs to erode in order to result in the "*complete elimination of any resistance to flow by the cement*"[21] [22] This volume was derived in Section 3.2. It is 38 cubic feet. We can, however, subtract the volume of the initially existing channels (19%), which would give us a volume of 30.8 cubic feet.

6.2 Government erosion rates

Griffiths assumes that any cement remaining in the wellbore at 21:30 would have been completely eroded nine hours later.[23] For his assumption to hold true, this means that approximately 30.8 cubic feet of cement would need to erode over a 9-hour period. To determine the erosion rate, one simply divides the volume of cement supposedly eroded by the time:

$$E_C = \frac{V_C}{9\,h} = \frac{30.8\,ft^3}{9\,h} = 3.42\,ft^3/h \qquad (6.1)$$

Here, E_C is the cement volume V_C (in ft^3) that must be eroded in a given time period (in hours). This calculation is charitable to Griffiths because he mentioned *"any resistance to flow by the cement <u>or other down-hole restrictions</u>."*[24] Thus, not just the designated cement volume must be removed during the 9-hour period, but additional material (with probably higher erosion resistances, say steel in the float collar) as well. And as noted above, there would also have been cement in the annulus resisting flow.

[21] Griffiths Report, page 12, n.11.

[22] It could be argued that resistance to flow may end before all the cement eroded. As we will see, however, the government experts require an erosion rate that is much higher than any reported cement erosion rates. This assumption thus does not affect our results and simplifies our analysis.

[23] Griffiths Report, page 12 ("9 hours represents ... the time to complete elimination of any resistance to flow by the cement...").

[24] *Id.*

If we apply the same calculation procedure to Dykhuizen's "2nd day criterion", we obtain:

$$E_C = \frac{V_C}{48\,h} = \frac{30.8\ ft^3}{48\,h} = 0.64\ ft^3/h \qquad (6.2)$$

6.3 The government experts' rates are thousands of times greater than any erosion rates reported in the literature on cement erosion

The government experts' assumed erosion rates are 10,000 to 100,000 times greater than any reported in the extensive literature devoted to concrete erosion. The Halliburton Lab Report mentions that the cement contains some silica sand.[25] That makes it different from a plain cement, because it contains aggregates and thus behaves like concrete. A situation very similar to channel flow was recently considered in the experimental work of *Wang et al.* (2012). They exposed concrete to water flow at a flow speed of 115 ft/s (35 m/s). The maximum erosion rate they estimated was about $169 \cdot 10^{-6}\ ft^3/h$. (This is .000169 cubic foot per hour.)

The addition of sand to the flow would increase the erosion rate. I have found evidence for this in investigations regarding the erosion of steel by oil-water-sand mixtures. For an oil-water-sand mixture with a sand content of about 20% by weight, the erosion rate increased by a factor of 9.[26] However, all results listed in *Table 6.1* account already for this mixed (slurry) flow. I have investigated erosion rates in concrete materials and exposed these materials to a high-speed slurry flow (like oil containing sand particles) at velocities of 180 ft/m.[27] The erosion rates I measured were about $254 \cdot 10^{-5}\ ft^3/h$. (That is .00254 cubic feet per hour.) More results from other researchers are provided in *Table 6.1*.

Even if the erosion rate is doubled due to the possibility that the well cement had a high porosity,[28] the complete erosion of the well cement would not occur in 2 days or anything close to that. The compressive strength numbers for the concrete materials cited in *Table 6.1* and those for the well

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[25] *See* Exhibit 7722.
[26] *Yang and Cheng, 2012*
[27] *Hu et al.*, 2002.
[28] *Atis, 2003.*

cements are of comparable order. In my earlier investigations,[29] I have found that a plain cement is sometimes easier to erode than a concrete material at very high flow speeds (v_F=720 ft/s). This is because of the lack of interfaces in the cement. (Interfaces would stop or branch cracks and slow down erosion.) However, the well cement in question contains some silica sand, and at least some of the well cement must be considered pre-damaged. These effects will reduce the differences between concrete and cement.

Results of erosion experiments on concrete materials are summarized in *Table 6.1.* The Government's assumed erosion rates are many times faster than rates reported in the literature. *That is, for these government experts to be correct, the cement in the well would have had to have to erode at least 100 times faster than the highest erosion rates reported in the literature.*

Table 6.1: Comparisons between erosion rates reported in the reference literature and erosion rates calculated from the expert reports

Source	**Reference**	**Material (compressive strength)**	**Water**	**Slurry**	**Flow speed** in *ft/s*	**Erosion rate** in ft^3/h
Expert Reports[1)]	*Griffiths* (2013)	Well cement [2)]				3.42
	Dykhuizen (2013)	Well cement [2)]				0.64
Experi-mental Results	Wang et al. (2012)	Concrete (10,900 psi)		X	115	0.00017
	Hu et al. (2002)	Concrete (4,400 psi)		X	180	0.0025
	Binici (2007)	Concrete (7,100 psi)		X	-	0.00046
	Liu et al. (2012)	Concrete (5,000 psi)		X	33	0.00071
	Hochheng and Weng (2002)	Concrete (5,100 psi)	X	X	50	0.00011
	Liu et al. (2006)	Concrete (2,900 psi)		X	33	0.00042
	Wu et al. (2010)	(Fibre reinforced concrete)		X	40	0.00078
	Yin and Xie (2011)	Concrete (4,350 psi)		X	256	0.0005

[1)] My calculations based on data from *Griffiths* and *Dykhuizen*;

[2)] Typical compressive strength numbers for the well cement are 3,918 to 4,575 psi *(Chevron*, 2010)

[29] *Momber and Kovacevic*, 1996.

7 Alternative scenario

7.1 Why an alternative scenario?

The possible rapid, early flow path increase cannot be explained with a standard erosion process, because it occurred much too fast. It seems that another material destruction process may be involved - namely hydraulic fragmentation, which I explore next.

7.2 Hydraulic fragmentation

We have shown the possibility that the cement initially had substantial flaws, such as a net of cracks or a number of capillaries, and a net of voids separated by cement bridges. We have also seen, based on the discussion of *Figure 5.1*, that there is a period where the oil flow rate in Emilsen's model changed from moderate numbers to higher numbers over a rather short period of time. This suggests the possibility of hydraulic fragmentation during some short period around the time the modelled flow rate increased. Hydraulic fragmentation is known from rock and concrete demolition.[30] It is similar to the well-known process of hydraulic fracturing, but is characterized by a local pressure increase over a short period of time, leading to the rapid fragmentation of, or internal damage to, a given material volume. Hydraulic fragmentation requires the existence of fluid-filled voids, flaws or capillaries and the sudden release of a particular pressurized fluid volume. It is possible that such a situation existed in the Macondo well prior to the incident.

The quick release of pressurized oil into a large pre-existing pore or into a pre-cracked section in the well cement due to the collapse of local cement bridges could result in fragmenting, creating pathways allowing the penetration of a substantial volume of oil in a short period of time.

Pressures as low as 3,770 psi, are sufficient to fracture concrete by means of hydraulic fragmentation.[31] But due to the lateral confinement of the cement volume in the steel pipe in the case of the Macondo well, the long cement column of about 189 feet, and the float collar and other equipment, the ejection of larger cement debris was prevented. This would have limited the

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[30] *Momber 1998, 2008*; *Hammelmann, 1996.*
[31] *Hammelmann, 1996.*

fragmentation process to the formation of a net of cracks and fractures; the fragmented cement likely would have been held in place, with a weakened structure that allowed fluid flow around the fragments. Thus, fragmentation likely would not have removed more than a small amount of the cement.

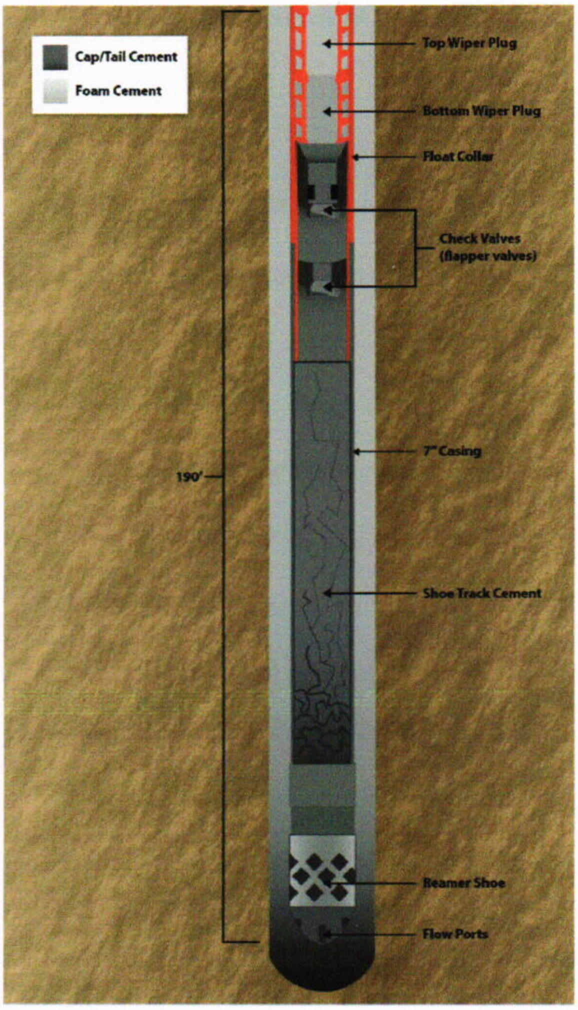

Figure 7.1

Schematic of the shoe track showing possible fragmenting of the cement. Also note the location of the "Foam Cement" in the annulus. Source material: BP, 2010.

Emilsen's modelling is also instructive. He gets a best match with the net pay of between 13 feet to 16.5 feet. As noted, Griffiths appears to conclude that this means there was a change of net pay from 13 to 16.5 feet over 30 minutes.[32] As I explained above, I do not see where Emilsen says this, but I will assume it for purposes of this discussion to provide a better explanation for what Griffiths reports. That is, assuming that Griffiths' assertion that net pay changed from 13 to 16.5 feet between 21:00 and 21:30 on April 20 were correct, such a change would not be consistent with an erosion process. But it would be consistent with a fragmentation process, in which all or most of the fragmented cement stayed in place with fractures allowing fluid flow, followed by an erosion process.

7.3 Alternative 4-step degradation scenario

The findings from the previous sections suggest a plausible explanation for what happened downhole. This alternative multi-step scenario consists of the following periods:

1. "Threshold" period: It is characterized by pre-damaged, permeable well cement, allowing the release of a small volume of hydrocarbons. This is consistent with the results of the negative pressure test.[33] During the threshold period, one would expect to see limited channelling and, hence, limited influx of oil into the wellbore.
2. "Initial" period: Hydraulic fragmentation of the pre-damaged well cement during the early period, generating flow paths through the cement. In the case of Macondo, the initial period is defined by a rapid increase in flow-path area for a short time period caused by fragmentation as described above.
3. Erosion period: Following the initial period of hydraulic fragmentation, I would expect to see a subsequent steady, gradual widening of the openings in the remaining cement due to slurry erosion (erosion caused by a mixture of oil and sand). This is consistent with a less intense increase in flow path size. As described in Section 6.3, cement erosion takes some period of

[32] Griffiths Report, page 11 (asserting that the increase in net pay took place between 21:00 and 21:30 on April 20 based on Emilsen's modelling).
[33] *See* Bly Report, Appendix W (noting that there was a possible hydrocarbon influx during the negative pressure of 0 to 20 barrels).

time to occur. We do not know for certain if this lasted for a week or a month or longer. Erosion is complicated, and the government experts have failed to address these key issues.

4. Final period: Effects of erosion are negligible.

This outlined scenario would account for a sudden release of oil, and for the initially steep increase in flow path cross section. It also would be consistent with a steady, gradual increase in flow path cross section, and the decreased contribution of erosion during the final period of the hydrocarbon release. Given the evidence, such a scenario is more likely than simply assuming that only erosion occurred - and that it occurred very rapidly.

8 Conclusion

In the end, the government experts do not provide arguments why and how cement erosion could have happened on the unprecedented timescales they posit. It is far more likely that there was an initial period of fragmentation followed by a long period of slower erosion. This erosive period may have lasted for a substantial portion of the spill.

The opinions that I have expressed in this report are based on my education, training, experience, and my review of materials in connection with this legal proceeding. I hold these opinions to a reasonable degree of engineering certainty.

I have not testified in the last four years, either in deposition or trial.

I am compensated for my time working on this matter at an hourly rate of $220, and my compensation is not related in any way to the outcome.

Submitted by:

A. Momber

Andreas Momber

May 1, 2013

9 References

Atis, C., 2003, Abrasion-porosity-strength model for fly ash concrete. *ASCE Journal of Materials in Civil Engineering*, No. 7/8, 408-410.

Binici, H., 2007, 2007, Effect of crushed ceramic and basaltic pumice as fine aggregates on concrete mortars properties. *Construction and Building Materials*, Vol. 21, 1191-1197.

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Yang, Y., Cheng, Y.F., 2012, Parametric effects on the erosion–corrosion rate and mechanism of carbon steel pipes in oil sands slurry. *Wear*, Vol. 276-277, 141-148.

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10 List of symbols

A_F	flow path cross section
A_W	well cement cross section
D_C	well cement column diameter
d_F	channel diameter
E_C	volumetric erosion rate
h_C	well cement column height
p	static pressure
Q_F	volumetric flow rate
v_F	flow velocity

11 Conversion factors (English to metric)

Area 1 inch²	6.45 cm²	
Length	1 inch	25.4 mm (2.54 cm)
	1 foot	0.305 m
Pressure	1 psi	0.007 MPa (0.07 bar)

Velocity	1 ft/s	0.305 m/s
Volume	1 ft^3	0.028 m^3

APPENDIX A

Estimate of flow path dimensions Section 5.2

The flow path dimension (d_F) is coupled to the pressure drop in the channel through the Darcy-Weisbach Equation:

$$\Delta H = f_D \cdot \frac{L}{d_F} \cdot \frac{v_F^2}{2 \cdot g} \qquad \text{(A1)}$$

Here ΔH is the head loss due to friction. Two simple relationships:

$$p = \rho_0 \cdot g \cdot H \qquad \text{(A2)}$$

$$Q_F = \frac{\pi}{4} \cdot d_F^2 \cdot v_F \qquad \text{(A3)}$$

help to rewrite Eq. (A1) as follows:

$$\Delta p_{\text{channel}} = \frac{8 \cdot f_D \cdot h_C \cdot \rho_0 \cdot (F_V \cdot Q_F)^2}{\pi^2 \cdot d_F^5} \qquad \text{(A4)}$$

Thus, if the pressure drop is known, the flow path diameter can be calculated. The parameters in Equation (A4) are defined as follows: Q_F=volumetric flow rate (which varied here); h_C=cement column height (channel length of 189 feet here); d_F=cross-section diameter open to flow (which we want to determine); ρ_0=fluid density (here, 587 kg/m^3); f_D=friction coefficient (here, 1 millimeter); F_V=formation volume factor (2.36 reservoir barrels of oil per stock tank barrel). The friction function $f_D(Re,\varepsilon,d_F)$ can be approximated with the Swamee-Jain Equation:

$$f_D(Re, \varepsilon, d_F) = \frac{0.25}{\left[\log\left(\frac{\varepsilon}{d_F \cdot 3.7} + \frac{5.74}{Re^{0.9}}\right)\right]^2} \qquad \text{(A5)}$$

In that equation, Re is the Reynolds number:

$$Re = \frac{v_F \cdot d_F \cdot \rho_0}{\mu_0} \qquad \text{(A6)}$$

Here, ρ_0= dynamic fluid viscosity (0.0017 Pa·s). (*See* Pencor Lab Report, BP-HZN-2179MDL01872218)

The next step is to establish a procedure for the estimation of $\Delta p_{channel}$. The pressure balance in the production system is as follows:

$$p_{res} - \Delta p_{Darcy} - \Delta p_{channel} = p_{bhp} \tag{A7}$$

The variables are defined as follows: p_{res} is the initial reservoir pressure; Δp_{Darcy} is the pressure drop from the flow in the reservoir to the sandface; p_{bhp} is the bottomhole pressure downstream of the cement.

The pressure drop from the reservoir to the bottomhole consists of two terms: the pressure drop from the reservoir to the sandface, and the pressure drop across the cement structure.

First, we have the pressure drop from the reservoir to the sandface, assuming the whole reservoir is open to flow:

$$\Delta p_{Darcy} = \frac{Q_{stb\ 21:30}}{PI} \tag{A8}$$

The subscript stands for the time 21:30, which we will use throughout this part of the calculation. This time marks the end of the period with moderate flow rate increase as discussed in Section 5.1; we have a flow rate of Q_F=12 stb/min at that time. PI is the productivity Index. We take PI=49 bbl/(day·psi) from *Emilsen* (2010), assuming full reservoir exposure. A rearrangement of Equation (A7) delivers:

$$\Delta p_{channel} = p_{res} - \Delta p_{Darcy} - p_{bhp\ 21:30} \tag{A9}$$

The first term is the initial reservoir pressure: p_{res}=11,856 psi. We can solve for the Darcy term by using Equation (A8), if we insert the flow rate. For $Q_F=Q_{stb\cdot 21:30}$=12 stb/min and PI=49 bbl/(day·psi), we obtain Δp_{Darcy}=353 psi. The bottomhole pressure can be calculated as follows:

$$p_{bhp\ 21:30} = p_{res} - \frac{Q_{stb\ 21:30}}{PI_{21:30}} \tag{A10}$$

At 21:30, the reservoir height was 13 ft in Emilsen's model. The productivity index scales linearly with the exposed reservoir (*Craft and Hawkins*, 1991, 247). We now assume that this effect is accounted for in the cement column. We also assume that there is no cement covering the reservoir. That delivers a modified productivity index:

$$PI_{21:30} = 49 \frac{\text{bbl}}{\text{day} \cdot \text{psi}} \cdot \frac{13\,\text{ft}}{86\,\text{ft}} = 7.41 \frac{\text{bbl}}{\text{day} \cdot \text{psi}} \tag{A11}$$

With $PI_{21:30}$=7.41 bbl/(day·psi) and p_{res}=11,856 psi, Equation (A10) delivers: $p_{bhp.21:30}$=9524 psi.
If all calculated numbers are inserted into Eq. (A9), we obtain a pressure drop over the channel of $\Delta p_{channel}$=1980 psi.

We introduce this number into Equation (A4) in order to calculate the corresponding flow channel diameter. This calculation procedure is performed also for the case of the highest flow rate Q_F=27 stb/min. The results of all calculations are summarized in *Table A1*.

Table A1: Results of flow channel size calculations

Parameter	Unit	Flow rate (Q_F) in stb/min	
		12	27
p_{res}	psi	11,856	11,856
Δp_{Darcy}	psi	353	794
p_{bhp}	psi	9,524	7,593
$\Delta p_{channel}$	psi	1,980	3,496
PI	bbl/(day·psi)	7.41	9.12
D_F	inch	2.17	2.64

APPENDIX B

Cirriculum Vitae

Andreas Momber

1 CONTACT

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	Germany
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2 PERSONAL DATA

- 1959	Day of birth: 16. March 1959
	Place of birth: Weißenfels (Sachsen-Anhalt)
	Name of birth: Andreas Bauda
- 1965 till 1973	Elementary school in Weißenfels
- 1974 till 1977	High school (Gymnasium) in Weißenfels
- 1977	Abitur
- 1977 till 1980	Military service in Weißwasser (construction engineering)
- 1980 till 1985	Study at the Hochschule für Architektur und Bauwesen Weimar

3 ACADEMIC QUALIFICATIONS

- August 2002	Habilitation (Dr.-habil.) at the RWTH Aachen, Faculty of Georesources and Materials Engineering), Aachen, Germany
	Referees:

- Prof. Dr. K. Nienhaus, Faculty of Georesources und Materials Technique, RWTH Aachen
- Prof. Dr. H. Louis, Institute of Materials Science, University of Hanover
- Prof. Dr. W.-D. Reinhardt, Institute of Construction Materials, University of Stuttgart

- February 1990	Promotion (Dr.-Ing.) at the Leipzig University of Technology, Department of Civil Engineering, Leipzig, Germany Referees: - Doz. Dr. J. Moritz, Department of Civil Engineering, TH Leipzig - Prof. Dr. G. Kuhnert, Institute of Process Machinery, University (Bergakademie) Freiberg - Prof. Dr. K-D. Röbenack, Chair for Construction Engineering, HAB Weimar
- February 1985	Diploma (Dipl.-Ing.) at the Hochschule für Architektur und Bauwesen Weimar, Department of Materials Processing Technology, Weimar Referee: Prof. Dr. S. Röbert
- 1980 till 1985	Studies in Materials Processing Technology at the Hochschule für Architektur und Bauwesen Weimar (University)

4 EMPLOYMENT

- Since 02/03	Muehlhan AG, Hamburg	Head of R&D Department
- Since 09/02	RWTH Aachen	Lecturer
- 01/99 till 06/02	RWTH Aachen	Habilitation Fellow
- 04/99 till 09/99	IRIS, Melbourne, Australien	Visiting Researcher
- 12/97 till 01/03	WOMA Apparatebau GmbH, Duisburg	Head Technology / Marketing
- 10/97 till 11/97	Southern Methodist University Dallas, TX, USA	Visiting Researcher
- 08/97 till 09/97	The University of Tulsa, Tulsa, OK,	Visiting Researcher

	USA	
- 12/95 till 07/97	WOMA Apparatebau GmbH, Duisburg	Head Technology
- 09/93 till 11/95	University of Kentucky, Lexington, KY, USA	Visiting Researcher
- 03/92 till 08/93	WOMA Apparatebau GmbH, Duisburg	Project Coordinator
- 04/91 till 02/92	University Hanover, Institute of Materials Science	Senior Researcher
- 03/85 till 03/91	Leipzig University of Technology, Leipzig	Research Assistant

5 TEACHING AND LEARNING

5.1 Teaching Areas

- Contact Mechanics
- Corrosion and Corrosion Protection
- Erosion
- Fracture Mechanics
- Materials Engineering
- Mechanical Material Processing
- Recycling
- Surface Science and Technology
- Tribology and Wear

5.2 External Engineering Education

- DECHEMA, Frankfurt, Germany, Germany
  http://www.dechema.de/en/start_en.html
- Deutsche Gesellschaft für Materialkunde (DGM), Frankfurt, Germany
  http://www.dgm.de/
- ForWind Academy, Bremerhafen, Germany
- Germanischer Lloyd, Hamburg, Germany
- Haus der Technik e.V., Essen, Germany
- NACE, Houston, USA
  http://www.nace.org/home.aspx
- Protective Coatings Europe, Genoa, Italy

- SSPC, Pittsburgh, USA

http://www.sspc.org/

- Technische Akademie Esslingen, Germany
- Technische Akademie Wuppertal, Germany
- Verein Deutscher Ingenieure (VDI), Düsseldorf, Germany

http://www.vdi.eu/

5.3 Supervision of Postgraduate Students

- Supervision of five Diploma Thesis
- Supervision of two PhD Thesis

6 RESEARCH (see also List of Publications)

- Coatings and coatings technology
- Corrosion and corrosion prevention
- Crushing and grinding of cement-based materials
- Fracture of quasi-brittle materials
- Mechanical testing of concrete materials
- Non-traditional machining techniques
- Recycling of construction materials
- Surface protection of construction materials
- Wear and erosion of geomaterials

7 AWARDS AND SCHOLARSHIPS

- 1991 Integration Grant of the Alexander von Humboldt-Foundation, Bonn, for Research at the Institute of Materials Science, University of Hannover, Germany
- 1993 First „Feodor Lynen"-Award of the Alexander von Humboldt-Foundation for Research at the Center for Robotics and Manufacturing Systems, University of Kentucky, Lexington, KY, USA

- 1994 Second „Feodor Lynen"-Award of the Alexander von Humboldt-Foundation for Research at the Center for Robotics and Manufacturing Systems, University of Kentucky, Lexington, KY, USA
- 1995 Third „Feodor Lynen"-Award of the Alexander von Humboldt-Foundation for Research at the Center for Robotics and Manufacturing Systems, University of Kentucky, Lexington, KY, USA
- 1995 Membership The New York Academy of Sciences
- 1997 Invited Visiting Researcher at the Department of Mechanical Engineering, The University of Tulsa, Tulsa, OK, USA
- 1997 Alexander von Humboldt-Foundation Exchange Fellow at the Department of Mechanical Engineering, Southern Methodist University, Dallas, TX, USA
- 1997 Member of the German Engineering Committee "Three Gorges" Dam Project, Yichang, PR China
- 1998 First nomination in Marquis' „Who's Who in Science and Engineering"
- 1998 Habilitation Declaration at the Department of Mining, Metallurgy and Geosciences, RWTH Aachen, Aachen
- 1999 Habilitation Grant of the Deutschen Forschungsgemeinschaft (DFG), Bonn, Germany
- 2000 Session Chair „Fluid Machinery", First Int. Congress on Mechanical Engineering, Shanghai, PR China
- 2001 DAAD Exchange Researcher at the University of Cambridge, Department of Physics and Chemistry, Cambridge, UK
- 2001 First nomination in Marquis' „Who's Who in the World"
- 2002 Invited Exchange Researcher at the University of Cambridge, Department of Physics and Chemistry, Cambridge, UK
- 2002 Venia Legendi (Privatdozent) for „Erosion", RWTH Aachen
- 2003 Nomination „Technology Award", WJTA, USA
- 2003 Front photograph: "Journal of Materials Science Letters"
- 2004 Editor's Award „Journal of Protective Coatings and Linings"
- 2004 Top Ten Paper of the journal "Wear"
- 2005 Invited Membership American Chemical Society
- 2007 Editor's Award „Journal of Protective Coatings and Linings"
- 2008 Invited Membership American Institute of Chemical Engineers
- 2009 SSPC Outstanding Publication Award
- 2011 SSPC: Listed as one of the 24 Industry's Top Thinkers in Surface Technology (Clive H. Hare Award)

8 ACADEMIC AND PROFESSIONAL LEADERSHIP

8.1 Referee to Scientific Journals

- ASCE Transactions
- ASME Transactions
- Colloids and Surfaces A: Physicochemical and Engineering Aspects
- Construction and Building Materials
- Experimental Fluid and Thermal Science
- IME Proceedings
- International Journal of Fracture
- International Journal of Impact Engineering
- International Journal of Mechanical Sciences
- International Journal of Materials and Product Technology
- International Journal of Mechanical Sciences
- Journal of Materials Processing Technology
- Journal of Materials Science
- Journal of Protective Coatings and Linings
- KSCE Journal of Civil Engineering
- Letters in Organic Chemistry
- Measurement Science and Technology
- Mineral Processing and Extractive Metallurgy
- Tribology International

Referee to Scientific Journals, cont.

- Tribology Transactions
- Wear

8.2 Referee to Research Organizations

- American Society of Mechanical Engineers, New York, USA
- Czech Science Foundation, Prague, Czech Republic
- Canada Research Chairs Program, Ottawa, Canada
- Deutscher Beton- und Bautechnik-Verein e.V., Berlin, Germany
- Deutsches Institut für Normung e.V., Berlin, Germany

- Forschungsvereinigung Bau- und Baustoffmaschinen e.V., Frankfurt am Main, Germany
- Germanischer Lloyd AG, Hamburg, Germany
- Institution of Mechanical Engineers, St. Bury, UK
- Institute of Materials, Minerals and Mining, London, UK
- National Association of Corrosion Engineers (NACE), Houston, USA
- Natural Sciences and Engineering Research Council of Canada (NSERC), Ottawa, Canada
- The Institute of Physics, London, UK
- The Society of Protective Coatings (SSPC), Pittsburgh, USA

8.3 *Chairmanship*

National Association of Corrosion Engineers (NACE)
Technical Committee TG 476
"Corrosion Protection of Offshore Wind Power Units"
Elected Chairman

8.4 *Offered Position*

Associate Professor of Sustainable Materials
School of Engineering
University of Western Sydney
Penrith, Australia
Offer rejected, February 2011

8.5 *Memberships*

- Deutscher Beton- und Bautechnik-Verein (DBV), Berlin, Germany
- Deutscher Hochschulverband, Bonn, Germany
- Deutsches Institut für Normung GmbH (DIN), Berlin, Germany
- Freunde und Förderer der RWTH Aachen e.V., Aachen, Germany
- National Association of Corrosion Engineers (NACE), Houston, USA
- The Society of Protective Coatings (SSPC), Pittsburg, USA
- Verband Deutscher Maschinen- und Anlagenbau e.V. (VDMA), Frankfurt am Main, Germany

APPENDIX C

Selected Publications 2000-2013

1. Books

1.1 Momber, A.W.: *Hydroblasting and Coating of Steel Structures*. Elsevier Applied Science, London, 2003.

1.2 Momber, A.W.: *Hochgeschwindigkeitserosion mineralischer Roh- und Werkstoffe*. („*High-speed Erosion of Geomaterials*"). Wissenschaftlicher Buchverlag, Osnabrück, 2004.

1.3 Momber, A.W.: *Hydrodemolition of Concrete Substrates and Reinforced Concrete Structures*. Elsevier Applied Science, London, 2005.

1.4 Momber, A.W., Schulz, R.-R.: *Betonoberfläche: Vorbereitung, Eigenschaften, Prüfung*. („*Concrete Surfaces: Treatment, Properties, Testing*"). Birkhäuser Verlag, Basel, 2006.

1.5 Momber, A.W.: *Blast Cleaning Technology*. Springer Publ., Heidelberg, 2008.

2. Journal Papers

2.1 Momber, A.W.: Concrete failure due to air-water jet impingement. *Journal of Materials Science*, **35** (2000), 2785-2789.

2.2 Momber, A.W.: The fragmentation of standard concrete cylinders under compression: The role of secondary fracture debris. *Engineering Fracture Mechanics*, **67** (2000), 445-459.

2.3 Momber, A.W.: The erosion of cement paste, mortar and concrete by gritblasting. *Wear*, **246** (2000), 46-54.

2.4 Momber, A.W., Kovacevic, R., Particle size distribution influence in high-speed erosion of aluminium. *Particulate Science and Technology*, **18** (2000), 199-212.

2.5 Momber, A.W.: Stress-strain relation for water-driven particle erosion of quasi-brittle materials. *Theoretical and Applied Fracture Mechanics*, **35** (2001), 19-37.

2.6 Momber, A.W.: Energy transfer during the mixing of air and solid particles into a high-speed waterjet: an impact force study. *Experimental Thermal and Fluid Science*, **25** (2001), 31-41.

2.7 Momber, A.W.: Fluid jet erosion of tension-softening materials. *International Journal of Fracture*, **112** (2001), 99-109.

2.8 Momber, A.W., Wong, Y.C., Budidharma, E., Tjo, R.: Hydrodynamic profiling and grit blasting of low-carbon steel. *Tribology International*, **35** (2002), 271-281.

2.9 Momber, A.W.: Surface issues of profiled cementitious composites. *The Journal of Adhesion*, **78** (2002), 203-221.

2.10 Momber, A.W.: The fragmentation of cementitious composites in a jaw breaker. *Theoretical and Applied Fracture Mechanics*, **38** (2002), 151-164.

2.11 Mohan, R., Momber, A.W., Kovacevic, R.: Energy dissipation control in hydro-abrasive machining using quantitative acoustic emission. *International Journal of Advanced Manufacturing Technology*, **20** (2002), 397-406.

2.12 Momber, A.W.: The wettability of some concrete powders. *Particulate Science and Technology*, **20** (2002), 243-246.

2.13 Hu, X.G., Momber, A.W., Yin, Y.G.: Hydro-abrasive erosion of steel-fiber reinforced hydraulic concrete. *Wear*, **253** (2002), 848-854.

2.14 Momber, A.W., Mohan, R.S., Kovacevic, R.: Fracture range detection in hydro-abrasive erosion of concrete. *Wear*, **253** (2002), 1156-1164.

2.15 Momber, A.W.: An SEM-study of high-speed hydrodynamic erosion of cementitious composites. *Composites - Part B: Engineering*, **34** (2003), 135-142.

2.16 Momber, A.W.: Cavitation damage to geomaterials in a flowing system. *Journal of Materials Science*, **38** (2003), 747-757.

2.17 Momber, A.W.: The efficiency of mechanical concrete comminution. *Engineering Fracture Mechanics*, **70** (2003), 81-91.

2.18 Weiß, M., Momber, A.W.: Preliminary investigations into the separation of automotive compounds by a hydro-erosive method. *Institution of Mechanical Engineers, Journal of Automobile Engineering*, **217** (2003), 221-228.

2.19 Momber, A.W., Kovacevic, R.: Hydro-abrasive erosion of refractory ceramics. *Journal of Materials Science*, **38** (2003), 2861-2874.

2.20 Momber, A.W.: Fracture lances in glass loaded with spherical indenters. *Journal of Materials Science Letters*, **22** (2003), 1477-1481.

2.21 Weiß, M., Wüstenberg, D., Momber, A. W.: Hydro-erosive separation of plastic fibres from textile compounds. *Journal of Materials Cycles and Waste Management*, **5** (2003), 84-88.

2.22 Momber, A.W.: Wear of rocks by water flow. *International Journal of Rock Mechanics and Mining Science*, **41** (2004), 51-68.

2.23 Momber, A.W.: Damage to rocks and cementitious materials from solid impact. *Rock Mechanics Rock Engineering*, **37** (2004), 57-82.

2.24 Momber, A.W., Koller, S., Dittmers, H.J.: Effects of surface preparation methods on adhesion of organic coatings to steel substrates. *Journal of Protective Coatings and Linings*, **21** (2004) 2, 44-50.

2.25 Momber, A.W.: Aggregate liberation from concrete by flow cavitation. *International Journal of Mineral Processing*, **74** (2004), 177-187.

2.26 Momber, A.W.: Deformation and fracture of rocks loaded with spherical indenters. *International Journal of Fracture*, **115** (2004), 263-279.

2.27 Momber, A.W.: Synergetic effects of secondary liquid drop impact on solid particle impact during hydro-abrasive erosion of brittle materials. *Wear*, **256** (2004), 1190-1195.

2.28 Hu, X.G., Momber, A.W., Yin, Y., Wang, H., Cui, D.M.: High-speed hydrodynamic wear of steel-fibre reinforced hydraulic concrete. *Wear*, **257** (2004), 441-450.

2.29 Momber, A.W.: Zur Optimierung von Plungerpumpen-Strahl-Systemen. *Engineering Research*, **68** (2004), 239-246.

2.30 Momber, A.W.: Eine Übergangsbedingung beim Strahlverschleiß von Gesteinen und Betonen. *Materialwissenschaft und Werkstofftechnik*, **35** (2004), 151-157.

2.31 Momber, A.W., Greverath, W.-D., Surface preparation standards for steel substrates - a critical review. *Journal of Protective Coatings and Linings*, **21** (2004) 2, 48-52.

2.32 Momber, A.W.: Beobachtungen an Gesteinen bei Eindruckversuchen mit runden Eindruckkörpern. *Engineering Research*, **68** (2004), 200-212.

2.33 Momber, A.W.: Deformation and fracture of rocks due to liquid impact at high speeds. *International Journal of Fracture*, **130** (2004), 683-704.

2.34 Momber, A.W.: Kavitationserosion von Werkstoffen für Wasserbauten. *Bautechnik*, **81** (2004), 819-824.

2.35 Weiß, M., Wüstenberg, D., Momber, A.W.: Erosive separation of organic coatings from fibrous substrates. *Journal of Environmental Management*, **73** (2004), 219-227.

2.36 Momber, A.W.: Eine elastisch-plastische Übergangsbedingung für die Tropfenschlagerosion von Gesteinen und Betonen. *Materialwissenschaft und Werkstofftechnik*, **35** (2004), 557-561.

2.37 Momber, A.W., Wong, Y.C.: Geometrical features of wear debris, part I: erosion of ductile steel by solid particle impingement. *Journal of Materials Science*, **40** (2005), 3517-3522.

2.38 Momber, A.W., Wong, Y.C.: Geometrical features of wear debris, part II: erosion of ductile steel by liquid particle impingement. *Journal of Materials Science*, **40** (2005), 1805-1808.

2.39 Momber, A.W., Wong, Y.C.: Overblasting effects on surface properties of low-carbon steel. *Journal of Coatings Technology*, **2** (2005), 453-461.

2.40 Momber, A.W.: Digital image analysis for assessing coated and uncoated surfaces. *Journal of Protective Coatings and Linings*, **22** (2005) 2, 53-56.

2.41 Momber, A.W.: A single-stage size-reduction process for the generation of fine-grained concrete. *Transactions of the Institute of Materials, Minerals and Mining*, **114** (2005), 121-127.

2.42 Momber, A.W., Koller, S.: Zur Korrosionsschutzwirkung von organischen Beschichtungssystemen auf gestrahlten Stahloberflächen. *Stahlbau*, **74** (2005), 780-787

2.43 Momber, A.W.: Der Werkstoffwissenschaftler Adolf G. Smekal: 1895 - 1959. *Engineering Research*, **70** (2006), 114-119.

2.44 Momber, A.W.: Ein Zerkleinerungskennwert für Betone. *Engineering Research*, **70** (2006), 120-127.

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2.46 Momber, A.W.: A transition index for rock failure due to liquid impact. Wear, 260 (2006), 996-1002.

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4.6 Momber, A.W.: Selective separation of plastic fibres from textile components. *Recycling of Plastics in Europe*, Institut für Werkstofftechnik, Universität Kassel, Kassel, Germany, June 2002.

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4.8 Momber, A.W.: Concrete in compression: failure and size effects. Invited Paper, *11th International Conference on Fracture*, Turino, Italy, March 2004.

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4.10 Momber, A.W.: Verfahren zur Vorbereitung von Metalloberflächen. *Seminar Korrosionsschutz - Grundlagen und Anwendungen*. DECHEMA, Frankfurt am Main, Germany, March 2005 + March 2006 + February 2008 + February 2010 + December 2011.

4.11 Momber, A.W.: Tribologie zementgebundener Baustoffe. *Wissenschaftliches Kolloquium Werkstoffe für das Bauwesen*, Universität Stuttgart, Stuttgart, BRD, Mai 2005.

4.12 Momber, A.W.: Image analysis methods for surface quality assessment. *Navy Production Panel Workshop*, Tampa, USA, February 2006.

4.13 Momber, A.W.: Techniques de décapage a ultra haute pression. Centre Français de l'Anticorrosion, Paris, France, April 2006.

4.14 Momber, A.W.: Assessment methods for steel substrate cleanliness prior to the application of organic coatings - a review of practice experience. Invited Paper, *5th International Symposium on Contact Angle, Wettability and Adhesion*, Toronto, Canada, June 2006.

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4.16 Momber, A.W., Plagemann, P., Stenzel, V., Schneider, M.: Application of electrochemical impedance spectroscopy (EIS) to marine coatings. *International Marine Coatings Summit*, Shanghai, China, October 2007.

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4.19 Momber, A.W.: Die Rolle mechanischer Oberflächenvorbereitungen im Korrosionsschutz. *45. Sitzung DGM-Fachausschuss „Mechanische Oberflächenvorbehandlungen"*, Kassel, Germany, April 2008.

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4.21 Momber, A.W.: Performance tests for coatings on offshore wind towers and over edges. *Institute of Corrosion*, Aberdeen Branch, Aberdeen, Scotland, February 2009.

4.22 Momber, A.W.: Scale and size effects. Invited Presentation, *12th International Conference on Fracture*, Ottawa, Canada, July 2009.

4.23 Momber, A.W.: Korrosionsschutz von Konstruktionen der maritimen Technik. *ZTV Oberflächentage 2009*, Zentralverband Oberflächentechnik, Bremen, Germany, September 2009.

4.24 Momber, A.W.: Advanced paints and coatings. Invited Session Speaker, *Marine Tech Summit - MTS 2010*, Dalian, China, October 2010.

4.25 Momber, A.W.: Korrosion und Korrosionsschutz der Tragstruktur von Offshore-Windenergieanlagen. *Bauteilschädigung durch Korrosion*, DGM Fortbildungsseminar, Cologne, Germany, December 2010/2011/2012.

4.26 Momber, A.W.: Device modelling, testing and development. Invited Session Speaker, *Low Carbon Earth Summit 2011*, Dalian, China, October 2010.

4.27 Plagemann, P., Momber, A.W.: Korrosionsschutz von Tragstrukturen für Offshore-Windenergie- anlagen. *14. Sitzung GfKORR-Arbeitskreis „Korrosion im Bauwesen"*, Helgoland, Germany, May 2011.

4.28 Momber, A.W.: Pipeline and riser technology. Invited Session Speaker (2.3), *2nd Annual Marine Tech Summit - MTS-2011*, Busan, South Korea, September 2011.

4.29 Momber, A.W.: Offshore wind farm construction status. Invited Session Speaker (2-4), *Low Carbon Earth Summit 2012*, Guangzhou, China, October 2012.

4.30 Momber, A.W.: Anti-corrosion for maritime industries. Invited Session Speaker (Forum 8), *The 1st Annual World Congress of Ocean - 2012*, Dalian, China, September 2012.

4.31 Momber, A.W.: Beschichtungssysteme für Offshore-Windanlagen - Untersuchungen und Erfahrungen. *Forum „Beschichtungen von Polymersubstraten und Beschichtungen für Anwendungen in der Kunststofftechnik“*, Internationale Fachmesse für Oberflächen und Schichten, Stuttgart, Germany, June 2012.

4.32 Momber, A.W.: Korrosionsschutz im Stahlbau. *DSTV-Seminar: bauforumstahl*, Düsseldorf, Germany, June 2012.

5. Patents

5.1 Momber, A.W.; Weiss, M.: Vorrichtung zum Trennen von Streifen von textilen Belägen in Faser- und Nichtfaseranteile. Patent Nr. 10107542, 18.02.2001.

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5.3 Siores, E.; Momber, A.W.; Chen, F.: Method and apparatus for machining and processing of materials. WO 01/03887 A1, 2001.

5.4 Greverath, W.; Momber, A.W.; Opel, H.: Optische Oberflächenprüfvorrichtung und ein Verfahren zur Beurteilung von Oberflächenzuständen, wie Struktur und/oder Farbintensität bzw. -vertei-lung, insbesondere von (un)beschichteten Stahloberflächen. Patent Nr. 03028778.3, 2004.

5.5 Greverath, W.; Momber, A.W.; Opel, H.: Device and method for testing surfaces, in particular steel surfaces, with respect to structure, colour intensity and/or colour distribution. WO 2005/ 057127 A1.

Appendix D

Consideration Materials

Consideration Materials
CVX80311 00000809
DJIT003_000129
BP-HZN-BLY00000201
HAL_0028709
BP-HZN-2179MDL03742328
BP-HZN-2179MDL02394186
BP-HZN-2179MDL02394187
BP-HZN-2179MDL04578104
BP-HZN-2179MDL04440732
BP-HZN-2179MDL04440689
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BP-HZN-2179MDL01872218
BP-HZN-2179MDL01872218
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BP-HZN-BLY00000208
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HAL_1126189
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HAL_DOJ¬_0000045
HAL_DOJ¬_0000049
CVX80311 00000809
DJIT003-000129
BP-HZN-2179MDL00269659
BP-HZN-2179MDL00269659
BP-HZN-2179MDL00360844
BP-HZN-2179MDL00360844
BP-HZN-2179MDL00640467
BP-HZN-2179MDL00640467
BP-HZN-2179MDL01299582
BP-HZN-2179MDL01299741
BP-HZN-BLY-00111338
BP-HZN-BLY-00111338
BP-HZN-CEC011406
BP-HZN-CEC011406
BP-HZN-2179MDL04578104
BP-HZN-2179MDL04578104

BP-HZN-2179MDL04440732
BP-HZN-2179MDL04440732
BP-HZN-2179MDL04440689
BP-HZN-2179MDL04440978
BP-HZN-2179MDL04440977
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