AP

CEAC-TR-01-0101

Progress, Challenges and Opportunities in the Application of Composites Offshore

K. Him Lo[1], Jerry G. Williams[2],
Metin Karayaka[3] and Mamdouh Salama[4]

[1]Shell International Exploration and Production Inc.
[2]Composites Engineering and Applications Center, University of Houston
[3]Aker Maritime Inc.
[4]Conoco Inc.

April 2001

COMPOSITES ENGINEERING AND APPLICATIONS CENTER
FOR PETROLEUM EXPLORATION AND PRODUCTION

UNIVERSITY OF HOUSTON
HOUSTON, TX 77204-0900

Technical Report CEAC-TR-01-0101

Progress, Challenges and Opportunities in the Application of Composites Offshore

K. Him Lo[1], Jerry G. Williams[2],
Metin Karayaka[3] and Mamdouh Salama[4]

[1]Shell International Exploration and Production Inc.
[2]Composites Engineering and Applications Center, University of Houston
[3]Aker Maritime Inc.
[4]Conoco Inc.

Composites Engineering and Application Center and
Department of Mechanical Engineering
University of Houston
4800 Calhoun Road
Houston, TX 77204-0903

April 2001

Progress, Challenges and Opportunities in the Application of Composites Offshore

K. Him Lo[1], Jerry G. Williams[2], Metin Karayaka[3] and Mamdouh Salama[4]

ABSTRACT

This paper provides an overview of the progress made in the past decade in offshore composites and addresses some of the remaining challenges and opportunities. A discussion of the key factors that influence the acceptance of composites for offshore operations is given. Advancements made to expand the usage of composites for both topsides and applications below the waterline are reviewed. The major near term challenge facing offshore composites includes successful implementation of the advanced composite products that have been developed in the past decade and development of regulatory guidelines specific to composites and the offshore oil industry. Potential opportunities for offshore composite applications still exist. However, a dedicated effort will be required during the next few years to insure that composites are included as an option by the oil and gas industry as it develops technology to explore and produce from ultra-deep water. Creative and innovative concepts and approaches are essential to the future success of offshore composites.

INTRODUCTION

Significant effort has been spent in the last decade to facilitate and increase the use of composites in the offshore oil industry. Reasonably good progress has been made to expand the usage of composites for topside components. The acceptance of composites by the offshore operators is also increasing. For deepwater applications, components made with advanced composites are beginning to emerge. Some advanced components such as high pressure riser accumulator bottles have already been used successfully in the field [1]. Other components such as the rigid composite production and drilling risers are now ready for deployment and sea trial [2-6]. Collaborative efforts between composite part suppliers, engineering and construction companies, academic and research institutes, offshore operators and various government agencies were essential to the progress made in the past decade. Although must work still remains to be performed, the advancement made in offshore composites in the past decade is clearly evident and has well positioned the oil and gas industry to expand the usage of composites in offshore operations in the coming decade.

[1] Shell International Exploration and Production Inc.
[2] Composites Engineering and Applications Center, University of Houston
[3] Aker Maritime Inc.
[4] Conoco Inc.

Some earlier developments in offshore composites were reported [7-11] in two previous conferences on *Composite Materials for Offshore Operations* [12,13] held in 1993 and 1997. The current paper provides a summary update of the progress made in the last decade in the application of composites offshore and discusses some of the remaining challenges and opportunities. The objectives of the paper are to stimulate discussion and thought on the future direction of offshore composites and to identify new research and development initiatives. Hence, the paper is not intended to be a comprehensive review of all current and potential future applications. To provide a common basis to address offshore composites, the paper begins with a review of some of the key factors that influence the acceptance of composites for offshore operations. This is followed by an overview of the development effort conducted during the past decade, a discussion on some near term challenges, and finally a discussion of some potential opportunities and challenges in offshore composites.

INCENTIVES FOR OFFSHORE COMPOSITES

It is generally perceived that offshore operators will accept the usage of composite components on their facilities if such usage can lead to improvement in project profitability, enhancement in operational safety, and/or provide enabling technology. Improvement in project profitability can usually be achieved through reduction in capital cost and/or reduction in operation and maintenance cost. For many applications, the material cost of an offshore composite component could be as high or higher than the steel counterpart. Hence, for new built facilities, improvement in project profitability may not be realized based on component cost alone. To demonstrate the ability of composites to provide cost benefits, consideration must be given to the overall installed cost of the component, the plausibility to reduce the overall system cost, the life cycle cost of the component, and the feasibility of using composite components to meet demanding project schedule. For the replacement of corroded parts on an existing facility, limiting the loss of production due to absence of hot work, improvement in overall system safety and reliability, reduction in maintenance cost, and improvement in payload capacity are factors which can permit composite components to be cost competitive.

As exploration and production of oil and gas move into deeper water, weight reduction becomes increasingly more important. It is clear that the lightweight characteristics of composites are well suited for deepwater operations. In addition, the high strength-to-weight ratio of advanced composites can be utilized to provide technical enabling solutions to assist the development of deepwater assets. However, in the rapidly changing economic environment experienced by the offshore oil and gas industry, acceptance of composite components for deepwater operations based purely on the merit of providing technically enabling solutions is usually difficult to justify. The composite component must also be sufficiently cost-effective to be profitable to the offshore operators. Hence, for deepwater operations, providing economical solutions is just as important as providing technical enabling solutions.

ACCEPTABLE COST OF OFFSHORE COMPOSITES

Table 1 provides an estimate of the relative cost range for offshore composite components that might allow them to be affordable for offshore implementation.

Table 1 – Relative Acceptable Cost of Offshore Composite Components.

Applications	Performance Requirements	Cost of product ($ per lb)
Most Topside Components	Moderate	2 – 5
High Performance Components e. g. production riser, tensioner accumulator bottle	High	10 – 20
Unique Performance Enhancing Applications	High	>20

The performance requirements of many topside composite components are relatively moderate and glass fiber composites are usually sufficient to meet the functional performance requirements. To provide economic benefits to the offshore operators and to be competitive with steel components, the cost per pound of these components needs to be in the $2-5 range. Even though the cost per pound of composite components might be higher than that of the steel components, actual economic benefits can still be derived due to their significantly lower weight and lower installation cost. Lower maintenance and life cycle costs also provide economic incentive. In general, composite topside components can be very cost competitive with steel components if the total installed cost of the component is take into consideration.

For more heavily loaded components such as the composite production riser and the composite accumulator bottle, carbon fiber is needed to meet the high performance requirements. Since carbon fiber is more expensive than glass fiber, design optimization and/or hybrid glass and carbon fiber construction must be considered to help reduce the cost of these components. For these composite components to be competitive with steel components, their cost will need to be in the range of $10-20 per pound of finished product. For certain limited unique applications such as downhole equipment; a higher cost per pound for the finished product may be acceptable.

The relative cost constraints given in Table 1 is intended only to provide a general picture of the perceived acceptable cost of offshore composite components. As the cost of traditional metallic components continues to improve, the pressure to lower the cost of offshore composite components will continue to be imposed.

PROGRESS IN OFFSHORE COMPOSITES

Composite Topside Components

As mentioned earlier, reasonably good progress has been made in the last decade to expand the usage of composites for offshore operations. Acceptance of composites for platform topside components is increasing. New and/or improved composite products have been developed and are now employed on various offshore facilities. The composite accumulator bottles [1], fire resistant phenolic composite grating [14], and new fiber glass piping for fire water main ring and dry deluge system [15] are a few examples of new composite products that have been developed in the last decade. These new products are fast becoming acceptable standard components on some new offshore facilities. Regulatory approval of composite topside components is gradually becoming less laborious, at least for some applications, by the development and issuance of new regulatory policy guidelines [16,17] that are relevant to the operating conditions of the offshore industry. Some new and/or improved industry standards [18,19] for offshore composite components are also beginning to emerge.

Valuable positive experience has also been gained with some of the newer topside applications. For example, the use of the hybrid composite accumulator bottles for the riser tensioner system clearly demonstrates that advanced composites can be used to provide high performance (3000 psi) while also providing cost-savings to the offshore industry. Well defined performance requirements, optimized design and manufacturing processes, together with firm commitment and support from the project engineers are the key factors to the successful development and deployment of this high pressure application. Over 200 accumulator bottles of various sizes are in service today on several deepwater facilities and some of them have seen active duty for over five years without incident. Similarly, the relatively new phenolic grating has also been used successfully on several offshore platforms for over five years without any problem. Significant component and system weight savings with no major installed cost penalty together with improved fire safety and worker's comfort are the key factors for the acceptance of the phenolic composite grating for topside applications.

Regulatory Guidelines for Topside Components

Regulatory approval plays a major role in the use of composites for offshore applications. As mentioned earlier, the recent development and issuance of new regulatory policy guidelines on composite grating and piping [16,17] by the United States Coast Guard (USCG) is a significant advancement in simplifying regulatory approval process for offshore composites. These guidelines represent an important step towards providing regulatory guidelines that are directly relevant to the offshore industry and allow type approval of offshore composites based on functional performance requirements and location of application on the platform. To demonstrate the impact of regulatory type approval on the acceptance and usage of composites, Tables 2 and 3 taken from [14] compares the significant usage of composite grating from one grating supplier before the issuance of the USCG Policy File Memorandum (PFM) on composite grating to the total usage in the first 12 months after the issuance of the PFM. It is clear that the acceptance of composite grating has grown significantly with the issuance of the functional and performance based guidelines provided in the PFM even during a period of difficult economic climate in the oil and gas industry. The development of new regulatory policy guidelines required a significant level of effort. Collaboration between suppliers and operators and the interest and cooperation of regulatory authorities was essential to the development of the PFM based on functional and performance merits.

Table 2. - Significant Composite Grating Usage (One Manufacturer) Before Issuance of the USCG Regulatory Guidelines.

Year	Type	Platform / Rig	Fire Performance Level	Used Quantity (square feet)
1979	Fixed	Ellen	None	10,000
1986-88	Fixed	South Pass 62A/D	None	~5,000
1991	Fixed	Ship Shoal 241 A	None	~8,000
1994-96	TLP	Mars **	"L3"	~90,000
1995	Fixed	West Delta 143A	None	40,000
1995-97	TLP	Ram Powell **	"L3"	99,960
1996	MODU-SS	Ocean Star **	"L3"	12,122
1997	MODU-SS	Celtic Sea	None	11,200
1997-98	Fixed	Spirit	None	9,326
1996-99	TLP	Ursa **	"L3"	213,000

** Indicates a case by case approval to similar a L3 level

Table 3 - Significant Composite Grating Usage (One Manufacturer) After Issuance of the USCG Regulatory Guidelines

Year	Type	Platform / Rig	Fire Performance Level	Used Quantity (square feet)
1998	SPAR	*Diana/Hoover	L2	+53,038
1998	MODU-SS	*Express	L2	+34,855
1998	MODU-SS	*Energy	L2	+34,855
1998	MODU-SS	*Cajun Express	L2	+34,855
1998	Fixed	West Delta 143B	None	+29,000
1999	FPSO	Petrobras P-40	None	+6,960
1999	MODU-SS	Glomar C.R. Luigs	L2	+10,855
1999	MODU-SS	Glomar Jack Ryan	L2	+10,855
1999	MODU-SS	*ENSCO 7500	L2	+9,580

1999	TLP	Brutus	L2	+100,000

* ABS Classified Vessel

+ Under Construction & May Require Additional Footage

Composite Components for Deepwater Applications

For deepwater operations, rigid composite production risers [4] and composite drilling risers [5,6] together with composite choke and kill lines [20] are being developed and qualified in several joint industry projects. These composite components are now available in standard offshore dimensions (Figures 1 and 2) and are available for deployment and/or sea trials. Other new composite components such as the continuous length spoolable composite piping, tubing and umbilical [21-23] and flexible risers with composite armor layers [24,25] are emerging and beginning to see active field services. These long length spoolable composite products represent major advancement made in composite tubular manufacturing and design concepts and will open new opportunities for more offshore applications [26]. Beside the components mentioned above, there are other composite components such as the carbon fiber composite tethers [27] and the composite buoyancy modules [28] that are still in various stages of research and development. Overall, the effort in the last decade has led to the development of multiple composite tubular products with high performance capabilities and the availability of long length manufacturing capabilities to meet the challenge of the oil and gas industry.

Research and Development Activities

The increased use of offshore composites has also benefited from the results of several focused research and development programs in offshore composites. Some of the important research organizations which have contributed to the advancement of composites technology for the petroleum industry include the Marinetech/Advanced Research Partnership program, Composites Engineering and Applications Center (University of Houston), Centre for Composite Materials Engineering (University of Newcastle upon Tyne), Offshore Technology Research Center (Texas A&M University and University of Texas), and Sintef Materials Technology (Norway). In addition, the National Institute of Standards and Technology's Advanced Technology Program has provided the catalyst for significant advancements in composite design technology and manufacturing capability and accelerated the availability of critical technology. These focused research and development programs together with the various product development activities significantly contributed to the advancement of offshore composites in the past decade. They also played an essential role to the increase acceptance of composites by the offshore operations.

Some General Comments on Past Development Efforts

Though corrosion resistance is an attractive feature of composites, it has not been the major driving force for most of the development efforts in offshore composites in the last decade. Instead, attention has been focused more on utilizing the weight saving potential of composites and on developing manufacturing technology for long length tubular to minimize the need of expensive connectors. The corrosion resistance of composites has generally been looked upon as a given characteristic of composites.

It is important to point out that the development activities in the last decade were consistent with the general thinking of the offshore industry [11]. Table 4 (taken from reference 11) shows that for a tension leg platform (TLP) significant system weight savings (an almost 3 to 1 ratio) can be achieved if composites are used for the platform topside components. Similar system weight saving leverage can also be obtained if composite risers are used in place of steel risers. Based on the results of Table 4, the research and development emphasis in the past decade on platform topside components and on risers and high pressure piping and tubing were very much on target with the perceived development priority of the offshore industry. Although the actual system weight savings that can be achieved on a TLP and on other floating production/drilling systems will depend on the system configuration [29], the results in Table 4 clearly indicate that judicious selection and use of lightweight offshore composites can bring significant system weight saving and cost benefits. These benefits have actually been realized with the use composite topside components in many offshore projects in the Gulf of Mexico.

Table 4 – TLP System Weight Savings Leverage.

Component	**Hull (ton)**	**Deck (ton)**	**Payload (ton)**	**Riser (ton)**	**Tether Pretension (ton)**	**Total Savings (ton)**
Hull	1.0	0	0	0	0.32	1.32
Deck	0.47	1.0	0	0	0.47	1.94
Payload	0.72	0.5	1.0	0	0.71	2.93
Riser	0.69	0.5	0	1.0	0.66	2.83

NEAR TERM CHALLENGES FOR OFFSHORE COMPOSITES

Implementation of Advanced Composite Products

The major challenge facing offshore composites in the near term is the implementation of the advanced composite products that have been developed in the past decade. For example, consider the rigid composite riser. After years of systematic research, development, and qualification, composite risers are now available for deployment and/or sea trial. Without a successful sea trial, it will be difficult to gain general acceptance of composite risers by the offshore operators. A challenge to field demonstration/deployment of composite risers is the need for properly developed installation procedures, credible inspection methods, and operation guidelines for these products. To facilitate general acceptance and successful deployment of these products, effort must be directed towards addressing these issues in the short term. A rush to deployment and/or field trial without properly addressing these concerns could lead to unexpected field failures which could hamper the acceptance of advanced composites for this and other demanding and critical offshore applications. A successful field demonstration and/or deployment, on the other hand, will truly demonstrate the utility, benefits, and cost-effectiveness of these composite products and will stimulate support of further research and development efforts for new applications.

In addition to properly developed installation procedures, acceptable inspection methods, and operation guidelines, appropriate industry standards must be developed for these products. These standards are needed to facilitate type approval of products by regulatory and certification agencies. However, before sufficient field experience has been accumulated, the development of an acceptable industry standard for a complex new component such as the composite riser is a significant challenge and needs to be addressed with careful planning. Such a standard should be performance based and reflect a thorough understanding of the current state-of-the-art composites technology. It should not be overly conservative or restrictive or place unreasonable burdens and requirements and unintentionally discourage the potential user from electing to use composites. Yet it must not allow unacceptable compromise on the safety and reliability of the component and its intended application. In addition, such a standard must be developed in close collaboration with product suppliers, end users, composites experts, and regulatory and certification agencies that have jurisdiction over the deployment and use of the component.

Relevant Regulatory Guidelines for Topside Components

To further increase the usage of available composite components for topside applications, effort is needed to accelerate the development of performance based regulations and guidelines that are relevant to the offshore industry. The PFMs [16,17] are good examples of such regulatory guidelines wherein the functional and performance requirements of a composite component are explicitly mapped with the service locations on an offshore facility. Certification agencies must also be involved in the development effort so that performance based regulations and guidelines will not be interpreted and applied in the same manner as the tradition prescriptive regulations and guidelines. More focused and collaborative efforts are needed for the development of relevant regulatory guidelines.

Lower Cost Products

The rapidly changing offshore oil and gas exploration and production scenario together with cost and performance improvement in conventional metallic components continues to apply pressure on the cost-effectiveness of composite products. Design optimization, manufacturing cost reduction, and improved installation methods still need to be pursued for composite components to remain cost competitive with the counterpart steel component. A positive factor for the development of advanced composites is the significant improvement made during the last decade in reducing the cost of carbon fiber. The lower cost of carbon fiber should help to reduce the cost of offshore composite components.

POTENTIAL OPPORTUNITIES AND CHALLENGES IN OFFSHORE COMPOSITES

There are still many challenges and opportunities for expanding the use of composites in the offshore industry [30]. A recent study conducted by CEAC [31] identified several promising applications that are of interest to the offshore community. A list of some of the components that could provide significant enabling capabilities for deepwater applications is given below. Several of these topics are discussed in the Third International Conference On Composites Materials for Offshore Operations.

1. Composite tethers and synthetic mooring ropes
2. Various composite risers
3. Thick-walled tubular for ultra high pressure pipeline and flowline
4. Double-walled insulated subsea pipeline
5. Long length, large diameter tubulars
6. Extended reach smart drill pipe
7. High performance thermoplastic pipe
8. Platform primary structure
9. Process vessels and tanks
10. Buoyancy Modules
11. Metal/composite hybrid structures

The development and successful deployment of these components will require new creative thinking and approach. For examples, primary deck structures, drilling derrick, and flare bloom are some obvious candidates for composites that can bring significant weight saving benefits [32]. For these components to be acceptable by the offshore operators they will have to be cost and functionally competitive with existing steel structures and be easily approved by regulatory agencies. Starting with the objective of achieving easy acceptance by both offshore operators and regulatory agencies, we must, therefore, question whether the convention composite design concept, fabrication method, and fire protection schemes are suitable for these components. New innovative concepts might need to be developed.

Figure 3 shows some common floating systems that are being used for deepwater exploration and production of oil and gas. Attention has been focused in the past mainly on developing composite risers and tethers to replace the steel components in these systems. Larger components like the hulls and pontoons of the TLP and the hull of the Spar has received limited attention [33]. The perceived obstacles for buoyancy components are their high manufacturing cost due to their larger size and their relatively low weight saving leverage potentials (Table 4). However, these components do present major opportunities for offshore composites. The main challenge is the ability to design and fabricate them cost-effective without major investment in new manufacturing technology and/or facility. To achieve this will require new innovative designs and modular construction methods to fabricate and assemble these components.

As exploration and production of oil and gas move into deeper water, subsea production systems become economically more attractive. The lightweight, corrosion resistant, and thermal insulation properties of composites made them attractive for subsea applications. Beside mud mats and wellhead protective structures, composites are suitable for such applications as subsea pipeline and flowlines, subsea storage facilities and subsea separation equipment. These applications represent significant opportunities for composites. As with other potential applications, cost-effective solutions are needed for these components to be attractive to the offshore industry.

There are still many opportunities in offshore composites. To capture these opportunities will require new creative and innovative design, fabrication, and assembly concepts. We must, therefore, fully utilize the performance characteristics of composites in the design of new applications and at the same time minimize the manufacturing cost of offshore composite components. Improved cooperation across various functional groups in the offshore industry including material engineers, platform designers and operators, part fabricators and suppliers, engineering and construction companies and regulatory agencies are needed. To expand the usage of composites, the objectives of these functional groups must be properly aligned so as to facility the implementation of new composite components on offshore facilities. Perhaps the most difficult challenge facing offshore composites is not only to identify and develop in-house composite champions in the operating companies but also to identify and develop composite champions in the various functional groups in the oil and gas industry. Despite a decade of active development and expand usage, there is still a need for the offshore industry as a whole to acquire a more uniform understanding of the performance characteristics and capabilities of composites. This need must be addressed in a timely manner for offshore composites to have a more expanded usage on offshore facilities.

REFERENCES

1. D. Baldwin, N. Newhouse, K. H. Lo, "High Pressure Composite Accumulator Bottle", Composite Materials for Offshore Operations – 2, S. S. Wang, J. G. Williams and K. H. Lo, Eds., American Bureau of Shipping, 1999, pp. 275-286.

2. P. Ordu and Guichard, "Design and Tests of High Performance Composite Tubes for Use in Deep Water Drilling Production Systems", OMAE Specialty Symposium on Offshore and Arctic Frontiers, M. M. Salama, Ed., ASME, 1986, pp. 353-359.

3. C. P. Sparks and J. Schmitt, "Optimized Composite Tubes for Riser Application. Proceeding of the Ninth International Conference On Offshore Mechanics and Arctic Engineering. Houston, TX. Vol. III. – Part A. Feb 18-23, 1990. pp. 1-8.

4. D. Baldwin, N. Newhouse and K. H. Lo, "Composite Production Riser Development", Composite Materials for Offshore Operations – 2, S. S. Wang, J. G. Williams and K. H. Lo, Eds., American Bureau of Shipping, 1999, pp. 115-128.

5. W. F. Anderson, J. J. Anderson, C. C. Mickelson, T. F. Sweeney, "The Application of Advanced Composite Technology To Marine Drilling Riser Systems: Design, Manufacturing and Test", Offshore Technology Conference Paper 8433, 1997.

6. J. Murali, M. M. Salama, O. Jahnsen, T. Meland, "Composite Drilling Riser – Qualification Testing and Field Demonstration", Composite Materials for Offshore

Operations – 2, S. S. Wang, J. G. Williams and K. H. Lo, Eds., American Bureau of Shipping, 1999, pp. 129-149.

7. B. W. Cole, "Petroleum E&P Industry Perspective on the Use of Composites in Offshore Operations". Composite Materials for Offshore Operations: Proceedings of the First International Workshop. NIST Special Publication 887. August 1995.

8. J. G. Williams, "Petroleum Industry Applications of Composites in E&P Operations". Composite Materials for Offshore Operations: Proceedings of the First International Workshop. NIST Special Publication 887. August 1995.

9. R. M. Vennet, J. G. Williams, K. H. Lo, P. Ganguly, "Economic Benefits Of Using Composites For Offshore Development And Operations", Composite Materials for Offshore Operations – 2, S. S. Wang, J. G. Williams and K. H. Lo, Eds., American Bureau of Shipping, 1999, pp. 3-16.

10. C. J. Houghton, Composites Use on Platform Topsides: A recent Case History and Future Prospects. Composite Materials for Offshore Operations – 2, S. S. Wang, J. G. Williams and K. H. Lo, Eds., American Bureau of Shipping, 1999, pp. 17-32.

11. F. J. Fischer and M. M. Salama, "Emerging and Potential Composite Applications for Deepwater Offshore Operations", Composite Materials for Offshore Operations – 2, S. S. Wang, J. G. Williams and K. H. Lo, Eds., American Bureau of Shipping, 1999, pp. 33-49.

12. Composite Materials for Offshore Operations: Proceedings of the First International Workshop. NIST Special Publication 887. August 1995.

13. Composite Materials for Offshore Operations – 2, S. S. Wang, J. G. Williams and K. H. Lo, Eds., American Bureau of Shipping, 1999.

14. T. Carlson, K. H. Lo, C. S. Myskowski, "Fire Performance And Regulatory Approval Of Glass Fiber Reinforced Composite Grating", Composites in Fire Conference, University of New Castle, 1999.

15. "Bondstrand PSX Piping For Offshore Fire Protection – Summary Report", Ameron International, 1996.

16. "Policy File Memorandum On The Use Of Fiber Reinforced Plastic (FRP) Gratings And Cable Trays", PSM 2-98, The United States Coast Guard, 1998.

17. "Policy File Memorandum On The Fire Performance Requirements For Plastic Pipe Per IMO Resolution A.753(18)", PSM 1-98, The United States Coast Guard, 1998.

18. "GRP Piping Specification and Recommend Practice", Proposed ISO document ISO/CD 14692.

19. “Standard Specification for Thermosetting Resin Fiberglass Pipe Systems To Be Used for Marine Applications”, Proposed Revision of ASTM F1173-95, 2000.

20. D. Johnson, D. Baldwin, L. Slaughter, “Composite Choke and Kill Line Development and Test Results”, CMOO-3, Houston, Texas, October 31-November 2, 2000.

21. D. W. McClatchie, H. A. Reynolds, T. L. Walsh, C. Lundberg, “Applications Engineering For Composite Coiled Tubing”, SPE 54507, 1999.

22. P.A. Quigley, H. Fowler, S. Nolet, and S. Berning, “Update On Composite Coiled Tubing Developments and Horizontal Well Applications”. Composite Materials for Offshore Operations – 2, S. S. Wang, J. G. Williams and K. H. Lo, Eds., American Bureau of Shipping, 1999, pp. 303-318.

23. P. A.. Haug, K. I. Ekeberg, “Dynamic Umbilical With Composite Tube (DUCT)”, Offshore Technology Conference Paper 8887, 1998.

24. M. Kalman, J. Belcher, “Flexible Risers With Composite Armor For Deep Water Oil And Gas Production”, Composite Materials for Offshore Operations – 2, S. S. Wang, J. G. Williams and K. H. Lo, Eds., American Bureau of Shipping, 1999, pp 151-165.

25. Alain Coutarel, Anh Tuan Do, Antoine Felix-Henry, “Weight Reduction Of Flexible Pipe By Using High Strength Composite Material”, Proceedings of ETCE/OMAE 2000, 2000.

26. J. G. Williams and Alex Sas-Jaworsky II, “Composite Spoolable Pipe Development, Advancements, and Limitations”. Offshore Technology Conference Paper 12029, Houston, Texas, May 2000.

27. M. M. Salama, O. Lindefjeld, O. F. Jahnsen, P-O Baalerud, “Composite Carbon Tether For Deepwater TLP Applications”, DOT 1999.

28. Private Communication with Fiberglass Structural Engineering, Inc.

29. R. Marthinussen, O. Jahnsen, H. Gulbrandsen, “The Influence Of Deepwater Production System Configuration On Composite Utilization”, Composite Materials for Offshore Operations – 2, S. S. Wang, J. G. Williams and K. H. Lo, Eds., American Bureau of Shipping, 1999, pp. 51-64.

30. J. G. Williams, “Composite Material Offshore Corrosion Solutions”. Workshop On Corrosion Control of Marine Structures and Pipelines. Galveston, Texas, February 1999.

31. J. G. Williams, ”Advanced Composites Technology Development For Ultra Deepwater Petroleum Production In The Twenty-First Century”. Technical Report, CEAC-TR-98-0106, CEAC, University of Houston, 1998.

32. A. Miravete, "A Preliminary Design Study Of Composite Flare Boom", Technical Report, CEAC-TR-98-0105, CEAC, University of Houston, 1998.

33. F. Botros, J. G. Williams, and E. Coyle, "Applications of Composite Materials In Deep Water Offshore Platforms". Offshore Technology Conference Paper 8500, Houston, Texas, May 1997.

Preprint of keynote address presented at Third International Conference On Composite Materials for Offshore Operations held in Houston, Texas on October 31- November 2, 2000. Paper to be published in book entitled *Composites for Offshore Operations – 3*, S. S. Wang, J. G. Williams and K. H. Lo, Editors.

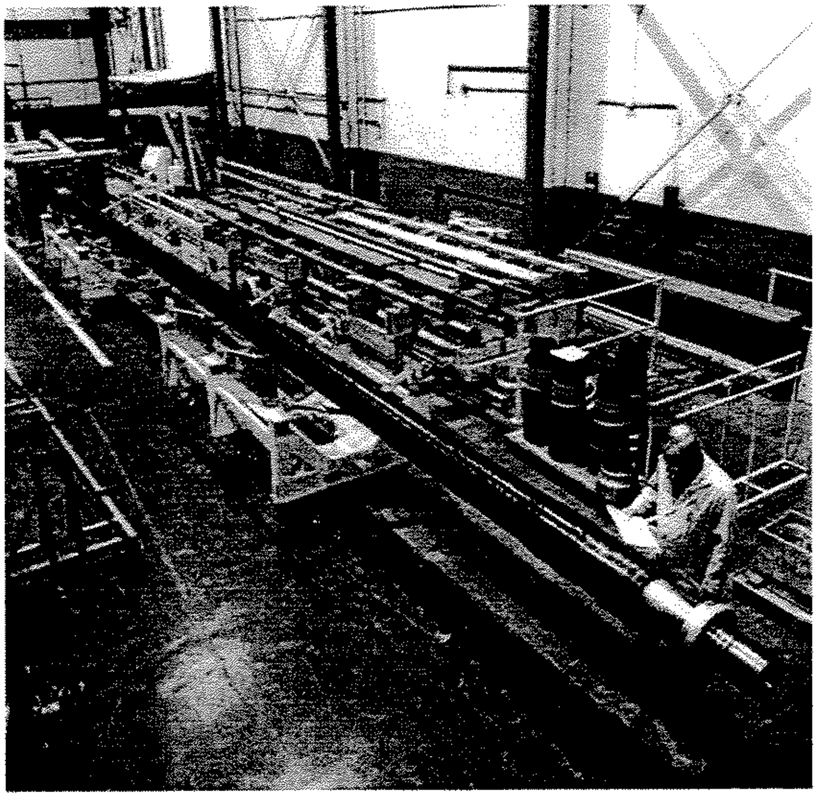

Figure 1. – **Long Length Composite Production Riser Test Sample. (Photo courtesy of Lincoln Composites)**

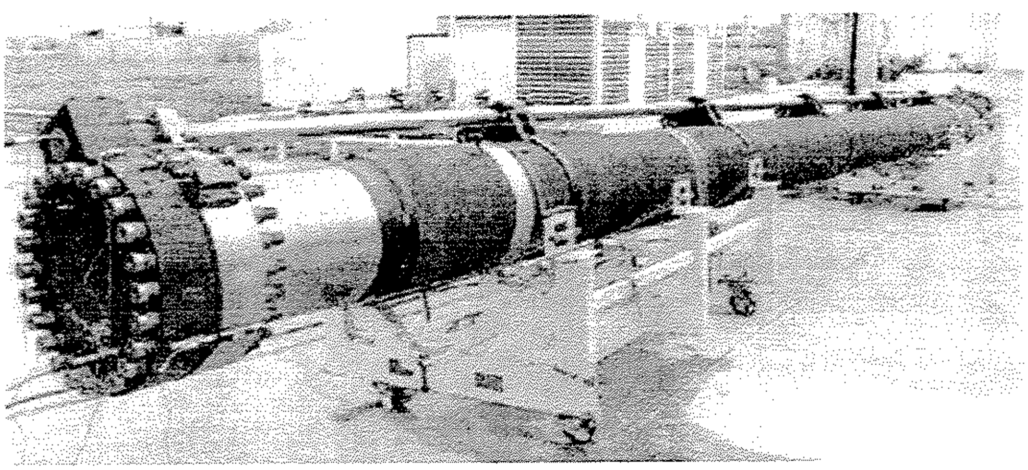

Figure 2. – Composite Drilling Riser Joint. (Photo courtesy of Lincoln Composites and Conoco Inc.)

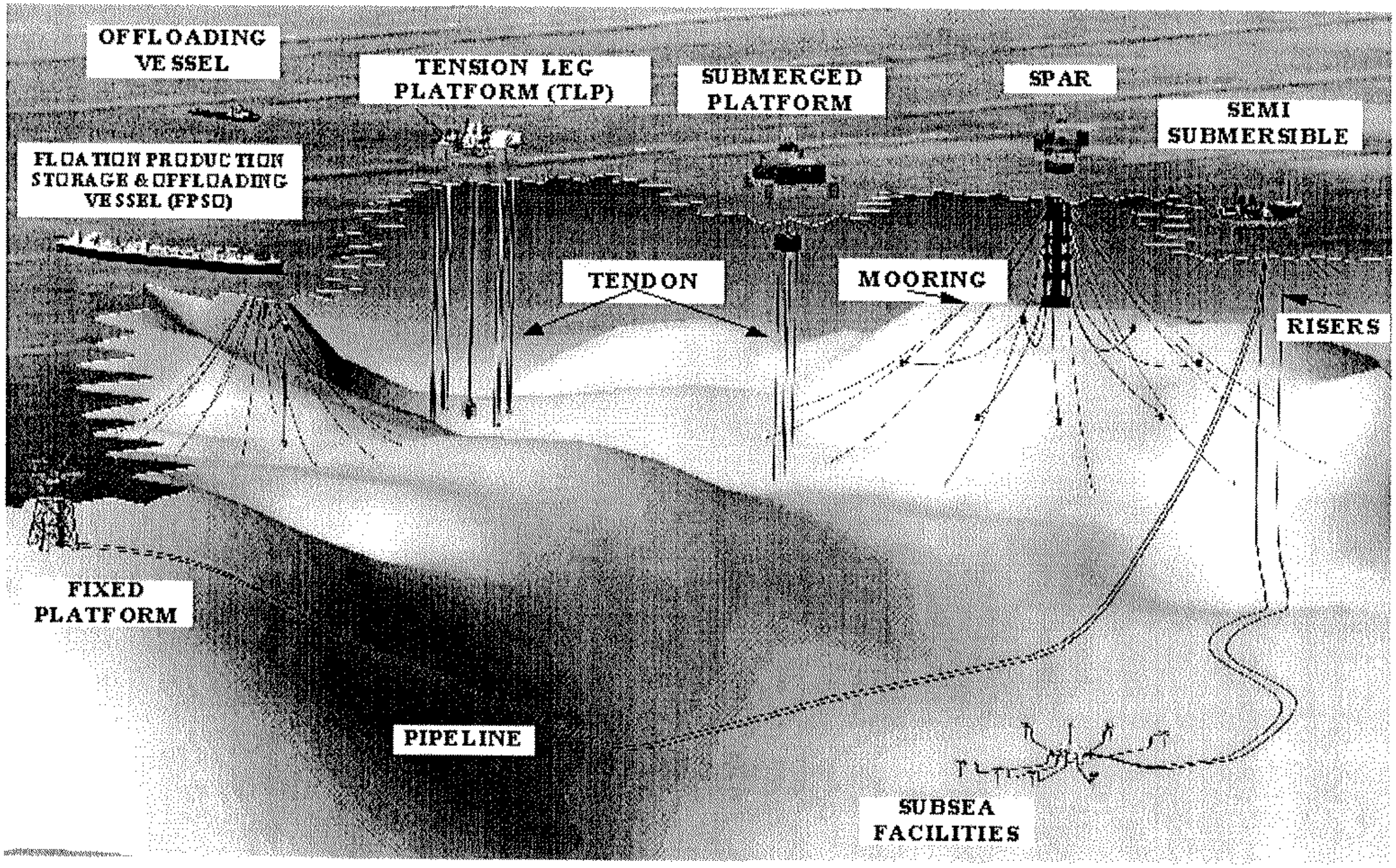

Figure 3. – Deepwater Production Systems.