Parallel-lay Aramid Ropes for Offshore Structures

G.B.Guimaraes

C.J.Burgoyne

Presented at – Brazil Offshore-89 Symposium

Engineering Department
Cambridge University
Trumpington St.
Cambridge CB2 1PZ

July 1989

PARALLEL-LAY ARAMID ROPES FOR OFFSHORE STRUCTURES

G B Guimarães
Pontifícia Universidade Católica do Rio de Janeiro

C J Burgoyne
University of Cambridge

INTRODUCTION

High strength aramid fibre ropes have already found several applications in the marine environment. They have been used as towing ropes and navigation buoy moorings for more than ten years and, more recently, they have been used to moor a construction ship during the erection of a guyed tower platform (Riewald, 1986). The interest in this material for offshore applications has grown considerably over the last years mainly because of its light weight, high strength, lack of corrosion and ease of handling.

Among the three basic constructions of fibre ropes, twisted, braided and parallel-lay, the latter has the highest strength, highest modulus and best fatigue performance achievable with a particular fibre. This paper is concerned with a particular parallel-lay rope, manufactured by Linear Composites Ltd, commercially known as Parafil. The development of this rope started in the mid 1960s as a result of a requirement for low weight non-corrodable cables for mooring deep water platforms across the North Atlantic (Kingston, 1988). Currently they are being considered not only for this sort of application but also for use in prestressed concrete, cable stayed bridges, cable roofs, rehabilitation of structures, etc (Burgoyne,1988).

It has been suggested that aramid ropes, such as Parafil, can be used with advantages as mooring systems for TLP platforms (Salama, 1984), for deep water semi-submersible platforms and as guy lines in guyed tower platforms (Baxter, 1988). Some of the advantages are, for example, the elimination of the cost associated with the provision of flotation systems along the mooring lines and cost associated with the corrosion protection which would be necessary for steel components.

The tension-tension fatigue properties of the ropes have been investigated (Crawford and McTernan, 1988), as have the tension bending characteristics (Burgoyne et al., 1989). These show that the ropes are ideally suited to offshore applications.

The thermal expansion, creep and stress-rupture behaviour of Parafil, which are relevant for offshore applications, are discussed in this paper. The discussion is based on partial results of an ongoing research program on the properties of the ropes aimed at their use as tension members in structures in general.

CHARACTERISTICS AND TENSILE PROPERTIES OF THE ROPES

The ropes used in this investigation, Type G Parafil, are formed of continuous Kevlar 49 yarns arranged in a parallel configuration and encased in a polymeric sheath. They are usually produced with nominal breaking loads within the range 1.5 to 150 tonnes, but ropes up to 1500 tonnes have already been produced and larger ropes up to 10000 tonnes are being designed (Kingston, 1988).

An important feature of the system is the termination, which consists of a cylinder with a conical hole into which a spike with a shallow angle is introduced to press the yarns against the cylinder. Tensile and stress-rupture tests have demonstrated that this system is efficient, with failure occuring along the rope length in the great majority of the cases, indicating that the terminal can develop the full strength of the rope, unlike many alternative systems.

The specific gravity of Kevlar is 1.44. In rope form, however, this figure reduces to about 0.98 due to the presence of air between filaments and the lower density of the sheath. If the rope is sealed at the ends, to prevent the penetration of water, it will float. If the rope is immersed in seawater and the core flooded, the specific weight will be around 200 kgf/m^3.

The stress-strain relationship for Type G Parafil is linear, with tensile strength of 1926 MPa, modulus of elasticity of 126000 MPa and strain at failure of 1.5%. The linearity of the stress-strain curve is observed only after the rope has been tensioned for the first time, after which any initial fibre disorientation is eliminated. A pretension of 5% to 10% of the nominal breaking load is sufficient to eliminate the non-linearity.

Information on the effect of temperature on the tensile properties of the ropes is still very limited. An indication of the behaviour of the rope can, however, be given by the existing data on Kevlar 49 yarns. This fibre does not melt but decomposes at around 460°C. Both tensile strength and modulus of elasticity reduce almost linearly with increasing temperature.

At 200°C, for instance, the tensile strength and modulus of elasticity of Kevlar are 70% of their values at room temperature. Additional information on the effects of temperature on the tensile properties of Kevlar can be found in Guimarães (1988a).

THERMAL EXPANSION

Many oriented crystalline polymers such as polyethylene, dacron, nylon 6 and polychlorophene have a negative coefficient of thermal expansion (CTE) in the chain direction and a positive one in the other two crystallographic directions (Wakelin et al, 1960). X-ray studies on Kevlar fibres (Ii et al, 1986) have shown that this material behaves in a similar way.

An experimental investigation on the macroscopic thermal expansion of Kevlar 49 yarns (Guimarães, 1988b) has revealed that the CTE of Kevlar 49 depends on the applied stress and becomes more negative as the stress increases. The experiments were carried out with the specimens immersed in distilled water within a range of temperatures from 5°C to 75°C and applied stress varying from 3% (88 MPa) to 45% (1222 MPa) of the tensile strength of the yarns. Table 1 shows some values of the CTE obtained from the tests. Since Parafil ropes consist of a bundle of parallel yarns, the values given in this table can also be applied to the ropes.

Table 1 - Coefficient of thermal expansion for Kevlar 49 yarns

Applied stress (MPa)	CTE* (10^{-6}/°C)
0	-3.7 ± 1.04
250	-4.6 ± 1.01
500	-5.5 ± 1.00
750	-6.4 ± 1.00
1000	-7.3 ± 1.02
1250	-8.2 ± 1.04

* 90% certainty

CREEP BEHAVIOUR

Creep data collected over periods exceeding 500 days, at room temperature (Guimarães, 1988b), have indicated that the creep strain of Parafil can be adequately described by a logarithmic time law, and that the creep rate at any time increases with stress. It was observed that the creep coefficient, defined as the ratio between the creep strain and the initial strain, can be considered stress independent, which means that the creep strain at any time is proportional to the applied stress. It was also found that the scatter of the experimental values of the creep coefficient can be described by the normal distribution. The confidence limits shown in Figure 1 were assigned, therefore, based on this statistical distribution. This figure shows that the creep coefficient is 0.11 ± 0.026 after 25 years, i.e., the creep strain after this period represents 11 ±2.6 percent of the initial strain.

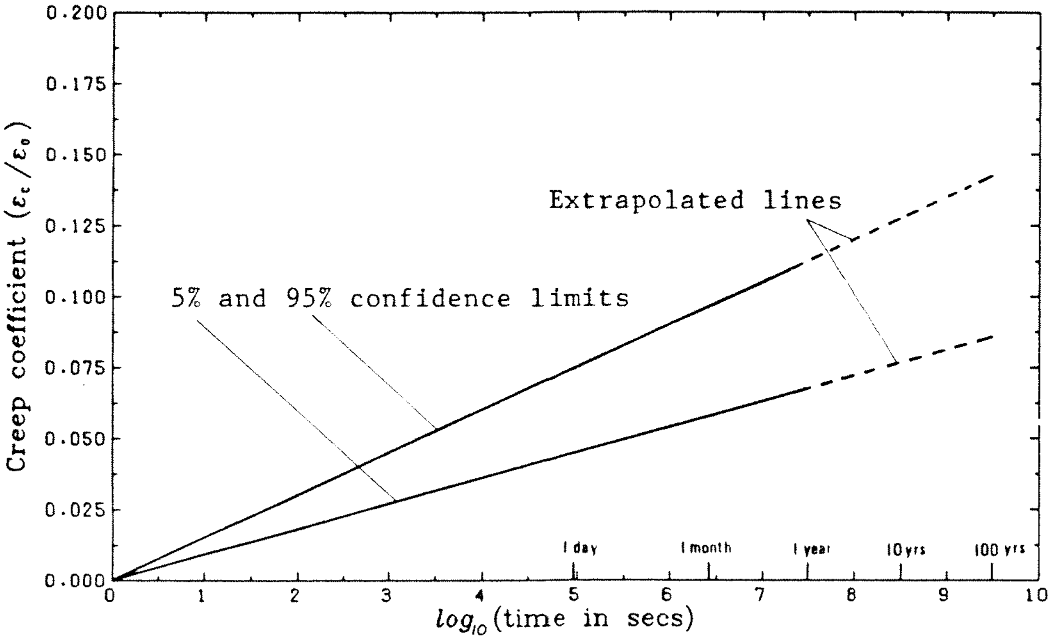

Figure 1 - Creep coefficient for Type G Parafil at room temperature

It must be pointed out that all the specimens in this investigation were conditioned before starting the tests, i.e., they were pretensioned to the same load used in the creep tests, unloaded and allowed to recover. Ericksen (1985) observed that, in multiple creep-recovery experiments on Kevlar 49 filaments, the first creep curve had the highest slope, while those for subsequent curves were lower and all the same. The slopes of the subsequent curves were on average 60% of the initial values and this ratio was independent of stress level. It is possible that the same phenomenon will also occur with Parafil and the creep coefficient values would be higher than those shown in Figure 1 if the ropes are not pretensioned before their use.

STRESS RUPTURE BEHAVIOUR

Stress rupture is the phenomenon of fracture which occurs some time after the application of a constant stress lower than the strength obtained in a test of short duration. This phenomenon is also referred to as creep rupture or static fatigue and is a characteristic of most materials when subjected to certain conditions of stress and temperature. At high temperatures, a variety of metals exhibit this phenomenon (see, for example, Tetelman and McEvely, 1967). Stress rupture is more important in polymers since it is exhibited at normal temperatures.

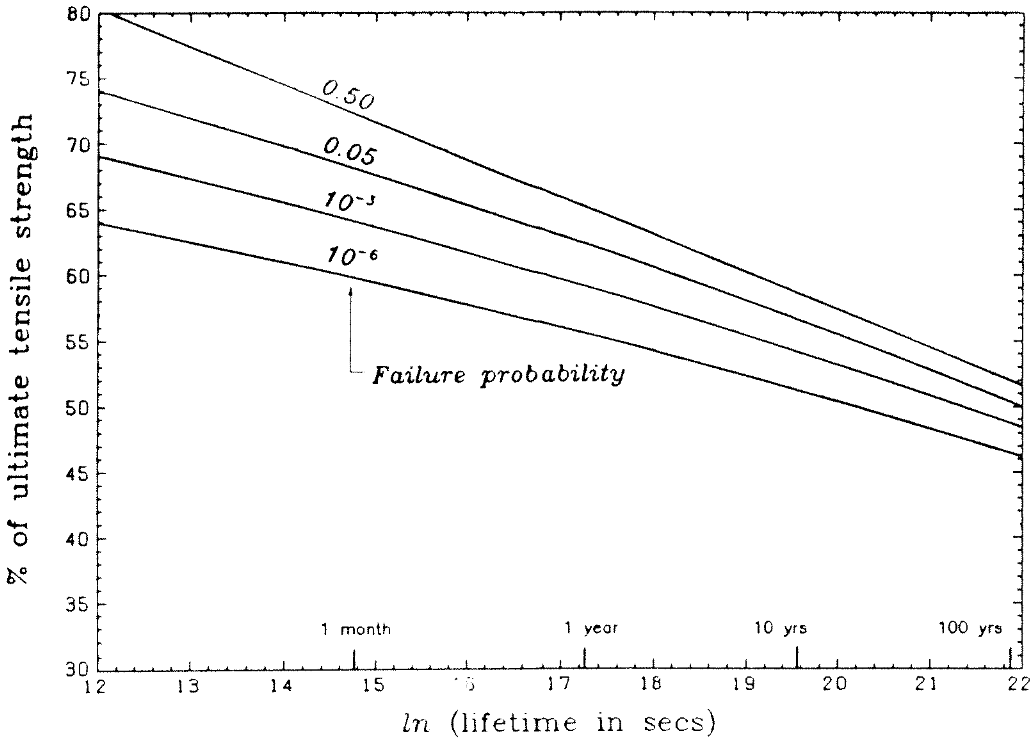

Figure 2 - Estimates of lifetime of Type G Parafil at room temperature

Stress rupture is usually characterized by a curve of stress against time-to-break and the knowledge of this curve is important to establish the working stress of the material as a function of the desired lifetime of the structure.

A number of stress rupture tests conducted on 1.5 tonnes, 3.0 tonnes (Guimarães, 1988b) and on 60 tonnes (Chambers and Burgoyne, 1989) Type G Parafil ropes, has been sufficient to identify general trends of the behaviour and to formulate a tentative statistical model for life prediction of the material. The tests were carried out at room temperature with the applied stress varying from 63% to 93% of the tensile strength of the ropes, and the corresponding times to break varied from a few hours to 9 months.

The statistical model was developed based on an exponential breakdown law combined with Weibull statistical methods to describe the scatter of the experimental data (Guimarães, 1988b). After determining the stress dependence of the parameters of the statistical distribution, an equation was established to estimate the lifetime corresponding to a given probability of failure. Figure 2 shows some curves for life prediction of Parafil, obtained from the model, for different probability levels.

A typical lifetime of an oil platform can be considered as 25 years; after this period, the failure probability of the ropes would be 10^{-6} for a working stress equivalent to 49% of the tensile strength as shown in Figure 2. For a probability of 10^{-3} the working stress could be increased to 54% of the tensile strenth.

CONCLUSIONS

The combination of properties such as light weight, high strength and modulus, good fatigue performance and exceptional resistance to corrosion, gives parallel-lay aramid fibre ropes great potential for use as mooring systems in offshore platforms.

A considerable knowledge of the properties of this material has been accumulated over the last few years, particularly on the long term properties such as creep and stress rupture. The data on these properties collected so far have been sufficient to formulate models capable of predicting creep and stress rupture behaviour with reasonable reliability which will be improved as more data are collected.

REFERENCES

Baxter, C. (1988) "Uses of Parafil ropes for mooring offshore platforms", Symposium on Engineering Applications of Parafil Ropes, ed. C J Burgoyne, Imperial College, London, Jan., pp 49-62.

Burgoyne, C.J. (1988) "Structural applications of type G Parafil", Symposium on Engineering Applications of Parafil Ropes, ed. C J Burgoyne, Imperial College, London, Jan., pp 39-48.

Burgoyne, C.J., Hobbs, R.E. and Strzemiecki, J. (1989) "Tension bending and sheave bending fatigue of parallel lay aramid ropes" OMAE Europe'89, The Hague.

Chambers, J.J. and Burgoyne, C.J. (1989) "An experimental investigation on the etress-rupture behaviour of a parallel-lay aramid rope", Journal of Materials Science, to be published.

Crawford, H. and McTernan, L.M. (1988) "Fatigue properties of Parafil", Symposium on Engineering Applications of Parafil Ropes, ed. C J Burgoyne, Imperial College, London, Jan., pp 29-38.

Ericksen, R.H. (1985) "Creep of aromatic polyamide fibres", Polymer, Vol. 26, May, pp 733-746.

Guimarães, G.B. (1988a) "Short-term properties of Parafil", Symposium on Engineering Applications of Parafil Ropes, ed. C J Burgoyne, Imperial College, London, Jan., pp 13-19.

Guimarães, G.B. (1988b) "Parallel-lay aramid ropes for use in structural engineering", PhD thesis, University of London.

Ii, T., Tashiro, K., Kobayashi, M. and Tadakoro, H. (1986) "X-ray study on lattice thermal expansion of fully extended aromatic polyamide fibres", Macromolecules, Vol. 19, pp 1772-1775.

Kingston, D. (1988) "Development of parallel fibre tensile members", Symposium on Engineering Applications of Parafil Ropes, ed. C J Burgoyne, Imperial College, London, Jan., pp 7-11.

Riewald, E.I. (1986) "Performance analysis of an aramid mooring line", Proceedings of Offshore Technology Conference, Houston, Vol. 2, May, pp 305-316.

Salama, M.M. (1984) "Lightweight materials for mooring lines of deepwater tension leg platforms", Marine Technology, Vol. 21, No 3, July, pp 234-241.

Tetelman, A.S. and McEvely, A.J. (1967) "Fracture of structural materials", John Wiley & Sons.

Wakelin, J.H., Sutherland, A. and Beck Jr, L.R. (1960) "Linear thermal expansion coefficients for the crystalline phase in high polymers", Journal of Polymer Science, Vol. XLII, Issue 139, pp 278-280.