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Materials selection for XL wind turbine support structures: A corrosion-fatigue perspective

Victor Igwemezie, Ali Mehmanparast*, Athanasios Kolios

Offshore Energy Engineering Centre, Cranfield University, Cranfield, Bedfordshire, England, UK

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ABSTRACT

The continued growth of the offshore wind industry will depend essentially on reductions in wind energy production cost. Large cost reductions can be achieved through efficient, economic and optimised wind turbine support structures. To achieve maximum offshore wind adoption beyond 2020, significant industrial and research efforts are being made in optimised material selection and application. Fatigue and corrosion damage are the greatest challenges today in design and life estimation of wind turbine support structures. S355 steel is currently used in fabrication of most wind turbine monopile support structures. Clear understanding of their corrosion-fatigue properties and accurate steel selection will support the optimisation and economic design of extra-large wind turbines. This paper presents the fatigue crack growth test results of advanced S355 TMCP steel in air and seawater, and compares the results with studies on commonly available S355 steel. The results show that S355 TMCP steels generally offer higher fatigue damage tolerance than normalised S355 steels in air and the factor decreases and tends towards a common value with increase in stress intensity factor range. However, in seawater there is no significant difference in fatigue crack growth rates for all the S355 ferritic steels considered in this study.

1. Introduction

The growth of the offshore wind industry will depend essentially on reductions in wind energy cost. Experience with the technology has revealed that environmentally friendly and economical wind energy can be produced by increasing the size of the turbine [1]. This simply means that the larger the turbine, the greener the electricity [2]. Consequently, offshore wind turbines (OWTs) are growing larger because of the need to push down the total cost of wind energy to a minimum. Previous studies have shown that further cost reduction could be achieved through efficient, economic and optimised turbine support structure, the dominant being the monopiles [3]. In the last few years, Levelised Cost of Energy (LCOE) target of £100/MWh was set to be achieved by 2020 [4]. In 2016, it was reported that the target of £100/MWh for offshore wind has been achieved 4 years before the target date [5]. The reduction was reported to be from £142/MWh to £97/MWh for UK projects reaching FID in 2015/16. Currently, Scotland has planned to add 1 GW in wind energy capacity. *Scottish Renewables*, the representative of the Scottish renewable energy industry, will be auctioning the new capacity from 2018/19 with clearing price expected to be £49.4/MWh in real 2017 terms [6].

Monopiles are the most commonly used wind turbine support structure due to their simplicity in design compared to other foundation concepts [7,8]. At water depths up to 30 m, monopile has clearly more commercial and technical advantages. It is well-suited for mass production as the installation method is based on conventional impact driving and is robust in most soil conditions

* Corresponding author.
E-mail address: a.mehmanparast@cranfield.ac.uk (A. Mehmanparast).

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Nomenclature

a_o	Initial crack length
a_f	Final crack length
σ_y	Yield stress
σ_{UTS}	Ultimate tensile stress
$\Delta\sigma$	Cyclic stress range
ΔK	Cyclic SIFR
da/dN	Fatigue crack growth rate (m/cycle)
$P_{\max}$	Maximum load
$P_{\min}$	Minimum load
K	Stress intensity factor (SIF)
R	Stress ratio
CFCGR	Corrosion-fatigue crack growth rate
FCG	Fatigue crack growth
FCGR	Fatigue crack growth rate
FID	Final Investment Decision
HAWT	Horizontal axis wind turbine
LEFM	Linear Elastic Fracture Mechanics
OWT	Offshore WT
SLIC	Structural Lifecycle Industry Collaboration Joint Industry Project
SIFR	Stress intensity factor range
SW	Seawater
TMCP	Thermo-mechanically control process
WT	Wind turbine
XL	Extra Large
PS	Present study

[3]. The literature has shown that the dominant majority of the commissioned offshore wind structures currently in use are supported by monopile structures while less than 10% are supported on jacket structures [9]. Although, many newly licensed wind farms in Europe, especially in UK Round 3 and Germany, to be developed before 2020 are at water depths below 40m, offshore activity is progressing towards deeper waters, requiring new design concepts to be considered. Despite these changes, monopile structures are maintaining interest from developers especially for large 10 MW concept designs [10–14]. Dong Energy (now Ørsted) and MHI Vestas in 2017 celebrated the installation of the world's biggest and most powerful wind turbine off the Liverpool coast. The 8 MW WT monopile is shown in Fig. 1(a), the steel material weighing about 1300 tonnes [15], while Fig. 1(b) is Gemini windpark monopile. Fig. 1(c) is the transition piece while Fig. 1(d) is the tower. The 600 MW Gemini windpark construction began in 2015 and was officially commissioned in 2017, having a total of 150 Siemens' 4.0-MW turbines. The monopiles used had dimensions of approximately 73 m in length and up to 7 m in diameter.

In the harsh offshore environment, where wind turbines (WTs) are subjected to constant exertion of cyclic wave and wind forces, it is essential to design the offshore wind turbine foundations against fatigue failure. The ultimate aim of fatigue design tests is to ensure that engineering structures perform optimally throughout their design life. Moreover, the offshore wind turbine foundations are in direct contact with seawater, hence introducing corrosion damage in the structure. Offshore WTs are relatively new structures and their long term corrosion fatigue performance data are scarce, or simply non-existent [17]. Although, wind turbines (WTs) are coated, there are periods when the coating peels giving rise to high rate of pitting and eventual crack formation. There are also many regions of the WT that are unprotected in which cracks could nucleate and grow. The presence of cracks could cause the WT

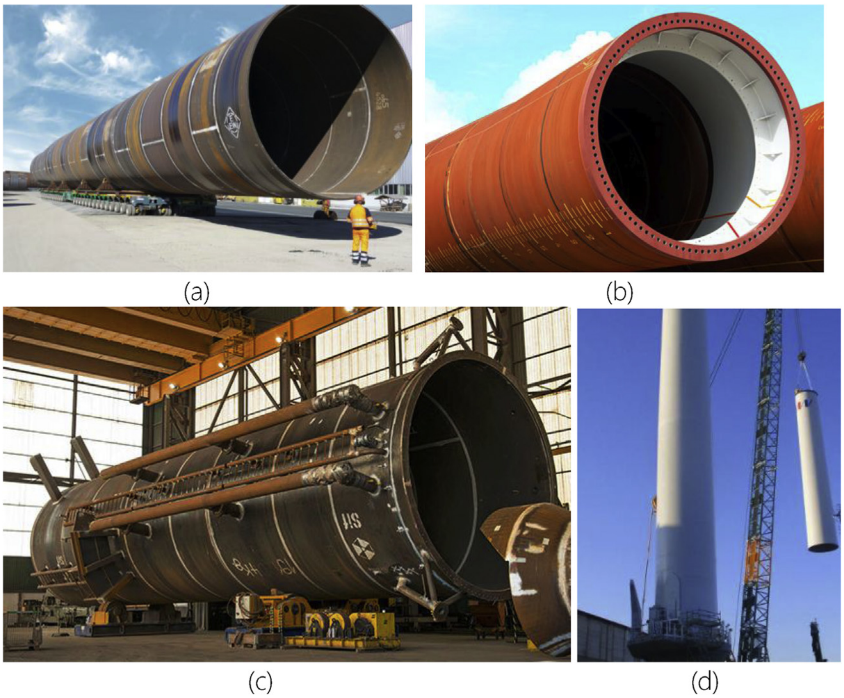

Fig. 1. Offshore WT support structures (a) 8 MW WT monopile, (b) Gemini windpark monopile, (c) transition piece, (d) tower [15,16].