Ice Accretion on Wind Turbine Blade – An Experimental Study of S819 Airfoil

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Abstract— **In order to gain the optimum wind power production from wind turbine operating in icing conditions, the aerodynamic performance of wind turbine blade profile is significant. Ice accretion on wind turbine blade changes its shape, which effects the blade aerodynamics and resultant power production. This paper presents an icing tunnel experimental study of ice accretion on S819 airfoil, designed by National Renewable Energy Laboratory (NREL). The experimental study is carried out at icing wind tunnel laboratory of Cranfield University, UK. S819 profile model with a span of 758 mm and chord length of 500 mm is used. Surface of blade profile model was made of Galvanized steel (VGAL.V.D×SID+Z275) with an average surface roughness of 0.9 microns. Experiments are carried out for both glaze and rime ice conditions at Reynold number = 3×10^6, Liquid Water Content =0.35 g/m^3 and Medium Volume Diameter of 20 µm. Complex horn type ice shapes are observed in case of glaze ice conditions that affects the aerodynamic performance differently from rime ice conditions.**

Keywords— **Icing tunnel, S819 airfoil, Wind turbine, Ice accretion, Experiments.**

I. INTRODUCTION

Wind energy in cold climate has gained interest of researchers and investors, but atmospheric icing on wind turbine blade is considered as a potential hazard in proper utilization of good wind resources available in ice prone cold climate regions. [1]-[2] By 2020 worldwide, installed wind energy capacity in cold regions will reach 123GW. [3]-[4] Wind energy losses in ice prone regions have been reported to lead up to a 17% decrease in Annual Energy Production (AEP) and 20% to 50% in the aerodynamic performance. [5] This highlights the importance of finding the better solutions for optimal operations of wind turbines in ice prone regions and also to have a good understanding of reducing Capital Expenditure (CAPEX) and Operational Expenditure (OPEX).

Ice accretion on wind turbine blade depends on both geometric (turbine size, shapes, and surface roughness) and operating (air temperature, wind velocity, Medium Volume Diameter (MVD) and Liquid Water Content (LWC)) conditions. Accreted ice shapes along blade profile have a significant effect on aerodynamic performance and flow behaviour. [6] Different temperatures and heat flux along the blade profiles will result in different ice accretion. [7] Duncan et al. [8] identified the difference between glaze and rime ice causing different levels of wind turbine power production losses.

There are three methods to study the ice accretion on wind turbine blade profiles: 1) experiments, 2) numerical simulations & 3) field measurements. Lab based icing wind tunnel experiments provided more accurate results of ice accretion as compared to numerical simulations, however, due to complex setup and expensive costs, not many icing tunnel based experiments of ice accretion on wind turbine blade profile has been carried out in last decades. In 2007, Wang et al. [9] have carried out wind energy losses for a NASA wind turbine model under glaze and rime icing conditions by using icing wind tunnel. In 2012, Han et al. [10] have done experimental study of NREL phase VI Rotor by using NASA Glenn Icing Research Tunnel (IRT). In 2016, Shu et al. [11] investigated the experiment study of the horizontal-axis wind turbine in China and focus on its ice accretion process. From 2017 to 2019, Gao et al. [12]-[13] and Jin et al. [14] have done the experimental study of ice accretion for DU96-W-180 airfoil, respectively. Besides, not much work has been carried out to study the performance of iced wind turbine blade profiles.

For this research work, S819 airfoil has been used. This airfoil is suitable for large horizontal axis wind turbine blade. Not much work has been carried out by researchers to understand the ice accretion physics along S819 airfoil. In the early stage, NREL has done the ordinary wind tunnel experiments to study the aerodynamic performance of un-iced clean S819 airfoil. [15] Recently, researchers from Chongqing University, China [16]-[17] have performed a series of studies at their natural icing station at Xuefeng mountain with S819 tapered and twisted blade and investigated the ice accretion feature and power characteristics of 300kW wind turbine. This paper describes an experimental case study of ice accretion along S819 airfoil for both wet glaze and dry rime ice conditions.

II. ICING TUNNEL SETUP

In this study, the experiments were carried out at the icing tunnel laboratory of Cranfield University (CU), UK. [18]

The icing tunnel facility at CU is able to create the realistic icing conditions at component level, which provide good information about ice accretion process. The atmospheric icing tunnel facilities consist of refrigeration plan room, control room, icing tunnel and many other important components. This icing wind tunnel has test section (761 × 761 mm) with 450 KW cooling capacity and can operate for Medium Volume Diameter (MVD) ranging from 15 to 80 µm. In addition, Liquid Water Content (LWC) from 0.05-3 g/m3 and air temperature from -30 to +30 °C. The Mach number should be controlled from 0.1 to 0.5 and main tunnel mass flow rate is 80 kg/sec. Fig. 1 shows the icing tunnel facility of Cranfield University.

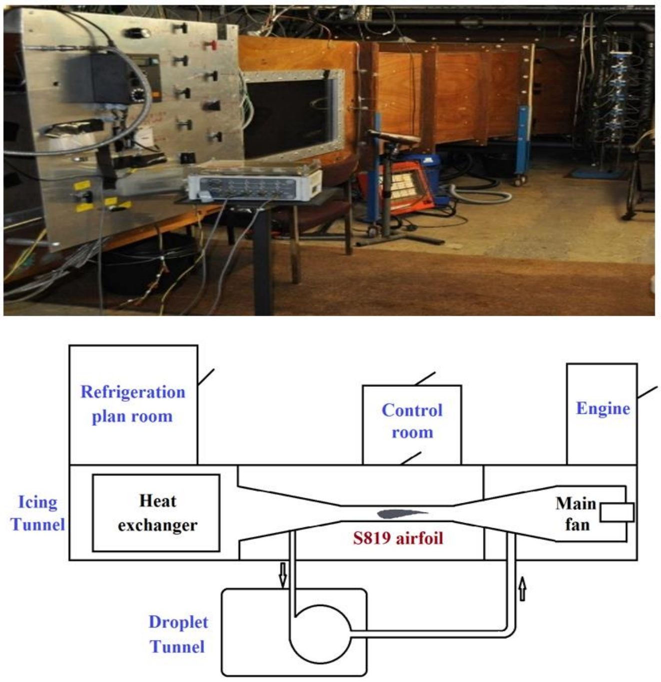

Fig. 1 CU atmospheric icing tunnel facility

For this experimental study, S819 wind turbine blade profile section with a span of 758 mm and chord length of 500 mm is used. The surface of blade profile model is made of Galvanized steel (VGAL.V.D×SID+Z275) with an average surface roughness of 0.9 µm. Fig. 2 shows the setup of icing wind tunnel and S819 profile section used for this study.

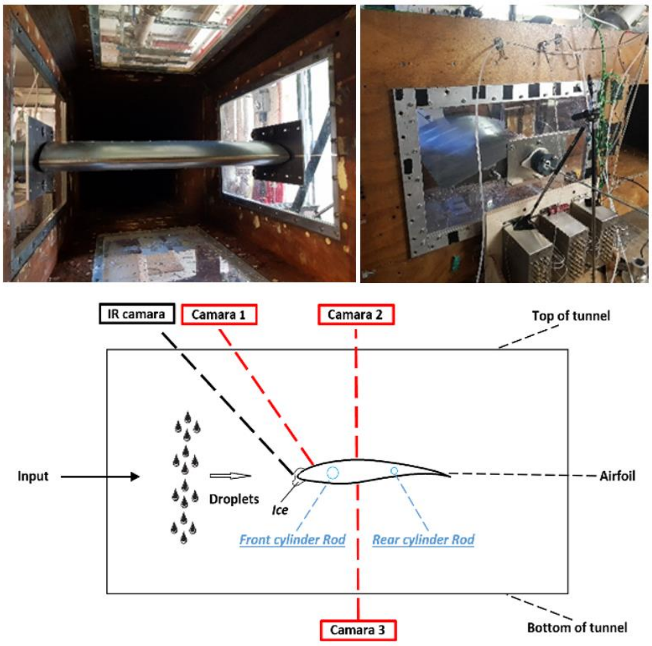

Fig. 2 CU icing tunnel setup for S819 test.

III. Icing Test Setup and Results

A. Experimental setup

To closely monitor the ice accretion along the blade profile, three High Definition [19] cameras (*two for side views and one from top view*) are used for video recording and pictures. The experiments are carried out at Reynolds number = 3×10^6 for both rime and glaze ice conditions. The accreted ice shapes are extracted and sketched after each experiments. Table 1 shows the operating conditions used for the experiments.

TABLE I. Icing tunnel operating conditions

Test	1	2
Ice type	Glaze	Rime
Velocity (m/s)	77	72
Temperature (^{0}C)	-5	-15
LWC (g/m^3)	0.6	
MVD (microns)	20	
AOA (degree)	0	
Icing time (mins)	15	

To closely monitor the icing wind tunnel operations, various operating parameters of CU icing wind tunnel are closely monitored to make sure the smooth operations. MVD of 20 microns is used with the droplet distribution spectrum consists of 60 bins. Fig. 3 shows the droplet distribution spectrum, variation of icing tunnel air speed and total air temperature at tunnel test section for both rime and glaze ice conditions.

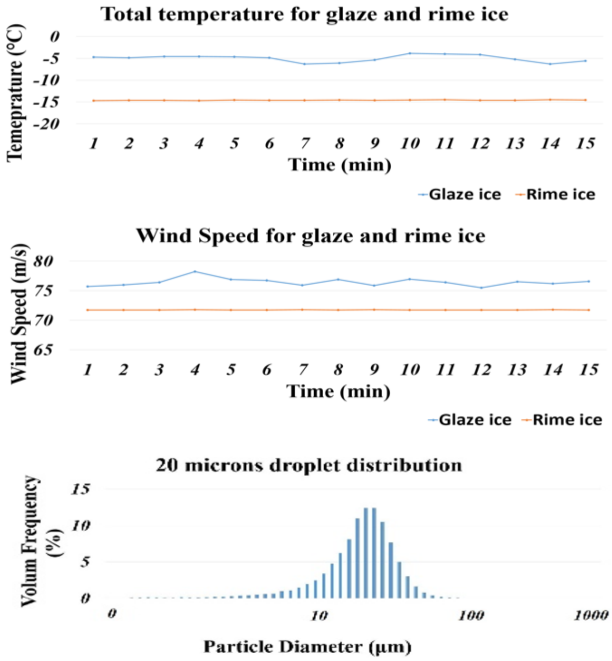

Fig. 3 Variation of wind speed, temperature, and droplet distribution spectrum in CU icing tunnel

B. Experimental results

Fig. 4 shows the experimental ice accretion with time where results show a significant difference in ice accretion for both rime and glaze ice conditions. Views from three HD cameras were used to monitor the ice accretion for this study.

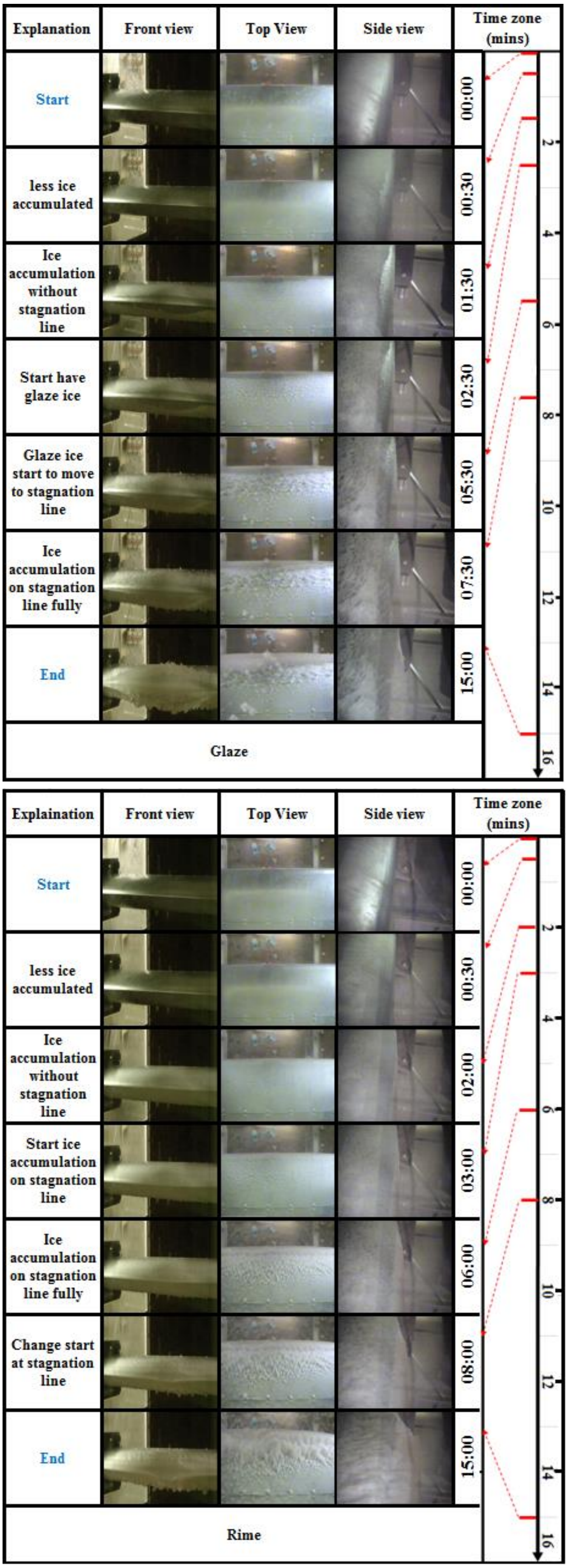

Fig. 4 Overview of experimental ice growth at various time steps for t=15 minutes at both glaze and rime ice conditions

Fig. 4 shows the ice accretion process at different time intervals for both rime and glaze ice conditions of S819 blade profile. In both cases, the results show that ice mainly accreted along leading edge of the blade profile. Analysis shows that for rime ice conditions, accreted ice was smooth and solid along stagnation line. For glaze ice conditions, the ice shapes splits into two horns which pointing perpendicular from the stagnation line, and two visible cracks at stagnation line some distance away from the centre of the model and ice colour differs from the either side of the crack (more white close to the wall and more opaque towards the centre of the model). For both cases, ice growth extended till 10-15% of the profile chord length, and large individual feathery spikes, pointing perpendicular to the profile surface is observed. After each experiment, the ice shapes were extracted from centre section of the blade profile. Table 2 shows the values of ice thickness and ice mass are found in both cases, and experimental ice shapes with cut-outs and ice thicknesses are shown in Fig. 5 which the complex horn type shapes are found in both glaze and rime ice conditions, more complex ice shapes are observed in glaze ice conditions.

TABLE II. ICING TUNNEL OPERATING CONDITIONS

Test	1	2
Ice type	Glaze	Rime
Ice thickness (mm)	29.25	33.25
Ice mass (g)	67	85.35

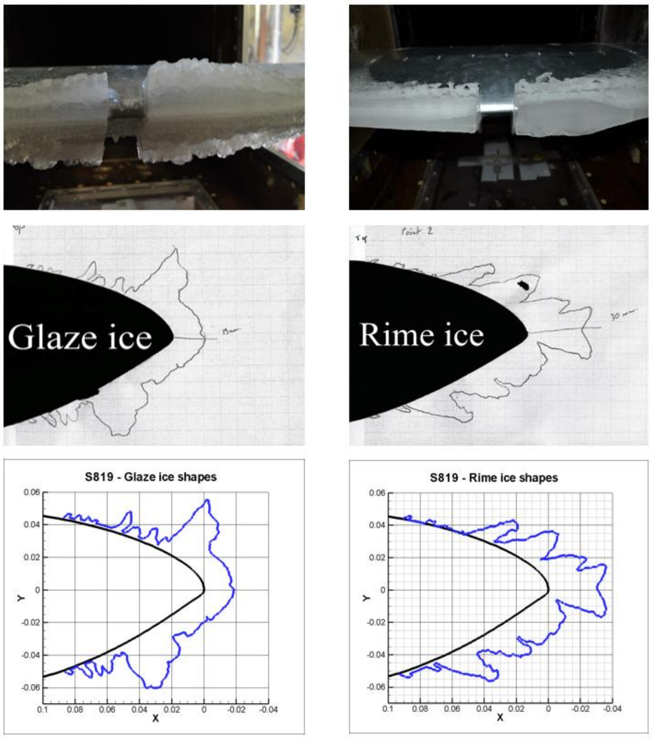

Fig. 5 Experimental ice shapes for glaze and rime ice conditions

IV. DISCUSSION AND CONCLUSION

In this paper, the experimental case study of ice accretion along S819 profile has been carried out using CU icing wind tunnel. For both glaze and rime ice cases, ice growth extended till 10-15% of the profile chord length, and large individual feathery spikes, pointing perpendicular to the profile surface is observed.

The experimental results show that ice thickness and ice mass are higher in case of in rime ice than glaze ice, which is mainly due to lower temperature.Results show that for wet glaze ice conditions, the ice shapes are more complex along leading edge when compared with the dry ice conditions. This is mainly due to the low freezing rate of the super cooled droplets impinging along the profile surface. For wet ice conditions, high aerodynamic drag along stagnation line of the blade profile pushes the non-freezing water droplets towards upper and lower sides of the profile surface, which resulted in horn shaped ice along leading edge. For dry rime ice conditions, all droplets freeze, which resulted in more streamlined ice shapes.

V. Future work

This paper describes an experimental study of S819 profile. Authors would like to further extend their investigations using Computational Fluid Dynamics (CFD) simulation of aerodynamic and physical performances studies in the future.

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