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AZIMUTHING PODDED PROPULSORS IN ICE: EXPERIMENT AND SOME RESULTS

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SUMMARY

With the advent of podded propulsors finding applications in vessels destined to operate in ice conditions, a need to better understand how these propulsion devices interact with the ice has been recognized. Subsequently, testing has been conducted at IOT on a characteristic model of Azimuthing Podded Propulsors in order that a method of predicting the loads these devices experience, in ice conditions, may be developed.

The following report briefly outlines the model Azimuthing Podded Propulsor, the method and extent of testing and some preliminary results for the Global system from testing the unit in pre-sawn level ice, pack ice and open water. The tests were conducted in Tractor and Pusher modes for ice thickness of 60 and 80 mm, depths of cut of 15 and 30 mm, and for a full range of azimuth angles.

Preliminary results indicate the mode of propulsion is fundamental in determining the magnitude of Global loads, with Tractor mode providing reduced Global loads. This mode also produces increased thrust and torque developed when compared to the Pusher mode. These results are based on mean loads and further analysis based on maximum loads, and the loads experienced by the propeller shaft and blades will result in a complete analysis on which to base a computational model.

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ABSTRACT

With the advent of podded propulsors finding applications in vessels destined to operate in ice conditions, a need to better understand how these propulsion devices interact with the ice has been recognized. Subsequently, testing has been conducted at IOT on a characteristic model of Azimuthing Podded Propulsors in order that a method of predicting the loads these devices experience, in ice conditions, may be developed.

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1 INTRODUCTION

Azimuthing podded propulsors although a fairly new technology have experienced wide industry acceptance with the result that their applications have expanded to include vessels operating in ice conditions as well as those vessels designed to operate in heavy ice/breaking conditions. As a result of this unforeseen growth in APP applications, a lag in knowledge pertaining to the loads experienced by the propulsion system has become apparent. The result has been acknowledgment that guidelines pertaining to the construction and operation of APP propulsion in ice conditions are necessary.

1.1 Objective

The purpose of the experiment "Azimuthing Podded Propellers in Ice – PJ01959" is to provide a means to calculate and predict the loads experienced by Azimuthing Podded Propulsors in ice conditions. The experiment has been designed to consider the loads experienced by the pod strut, propeller shaft and bearings, and one of the propeller blades. The developed method for predicting loads will be used in order that Transport Canada may establish guidelines for the construction and use of APP equipped vessels in ice conditions.

1.2 Azimuthing Podded Propulsors

Azimuthing podded propulsors consist primarily of a streamlined pod hung from a vessels hull, typically at the stern, by a strut. The pod is equipped with a propeller on the front or rear or both, depending on the manufacture of the podded assembly. Propulsion is provided by some form of machinery internal to the ships hull driving the pod directly through mechanical systems or indirectly through a generator and an electric motor housed within the pod itself. The pod and strut are fitted to rotate about the struts vertical axis, thus permitting the directional control of the developed thrust, as well as acting as a control surface.

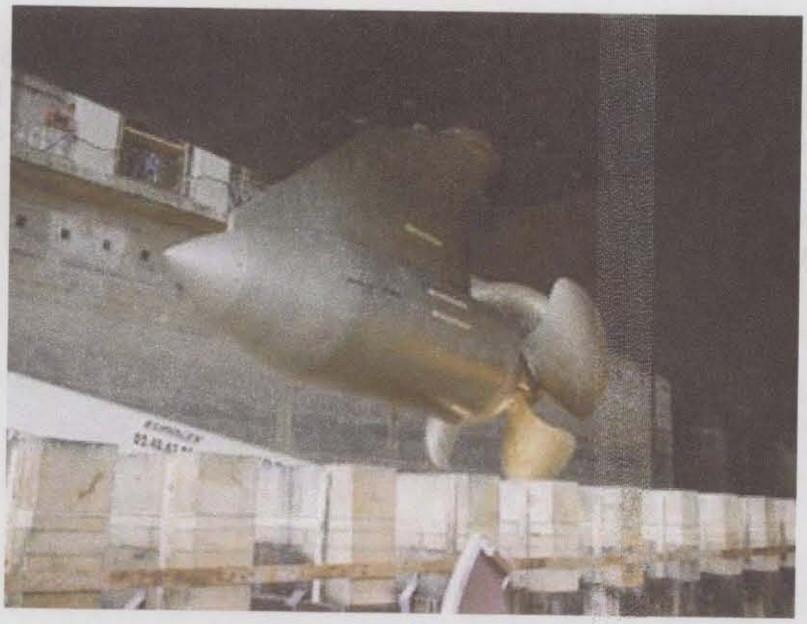


Figure 1. 19.5 MW Mermaid System
http://www.marinelog.com/DOCS/PRINT/mmipods2.html

2 EQUIPMENT AND FACILITIES

2.1 IMD Ice Tank

The tank has an overall length of 90m and width of 12m with a depth of 3m. The test section is 76m long and may be separated from the 15m preparation area during freezing by a thermal barrier door. At the opposite end of the tank is a melt pit to recycle ice and the additive back into the tank.

A Service carriage and Towing carriage are available. The Service carriage is used for ice control and measurements and has a maximum speed of 0.5 m/s. The Tow carriage is

80 tonnes with a temperature and humidity controlled control center, which houses the data acquisition equipment. The carriage is powered a 4 wheel synchronous motor drive, with a speed capability of 0.0002 – 4.0 m/s. The test frame is adjustable transversely and vertically, allowing maximum use of the ice sheet.

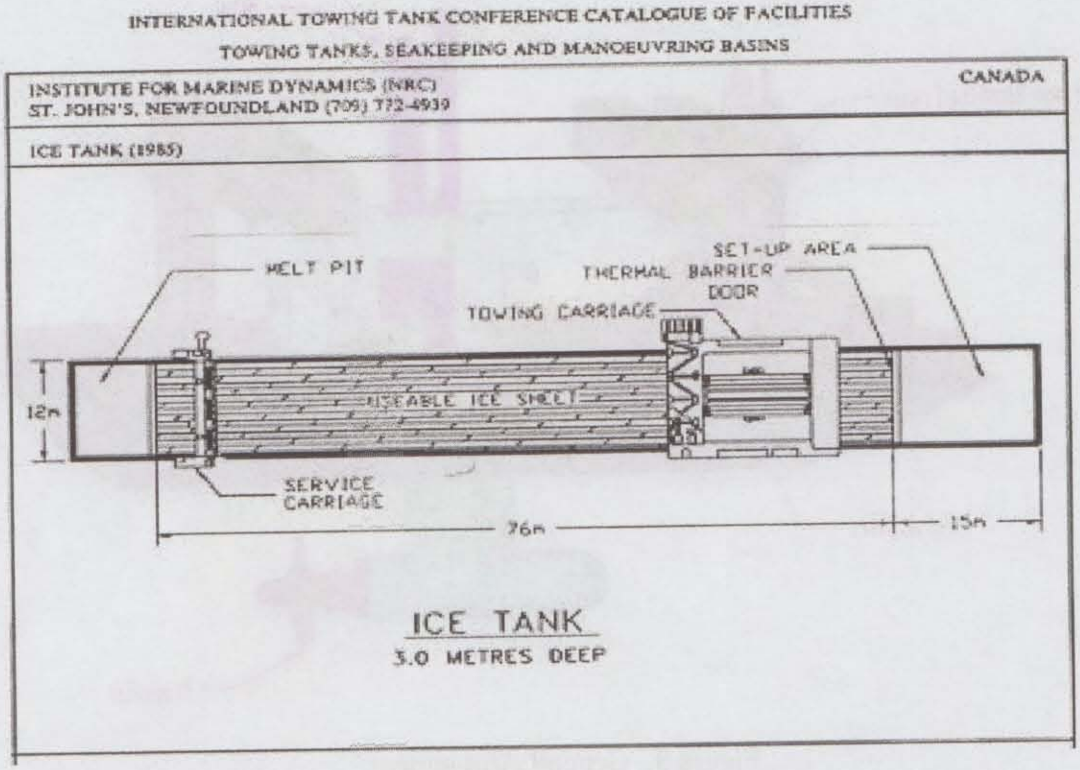


Figure 2. Ice Tank Schematic.
http://iot-ito.nrc-cnrc.gc.ca/photos/icetank_diagram1.jpg

2.1.1 Ice

The Ice Tank has an operating temperature range of -30°C to 15°C, and growing ice at 3.00mm/hr at -25°C, with ice sheet thickness varying from 10mm to 150mm. The ice used is an NRC development, EG/AD/S CD, which stands for Ethylene Glycol Aliphatic Detergent Sugar Corrected Density. The ice is characterized by a fine columnar or cylindrical grain structure, with a flexural strength ranging from 10 – 120 Kpa.

2.2 Test Apparatus

The general arrangement of the false stern with the leg and pod sticking out below the false bottom is shown in side view in Figure 2.

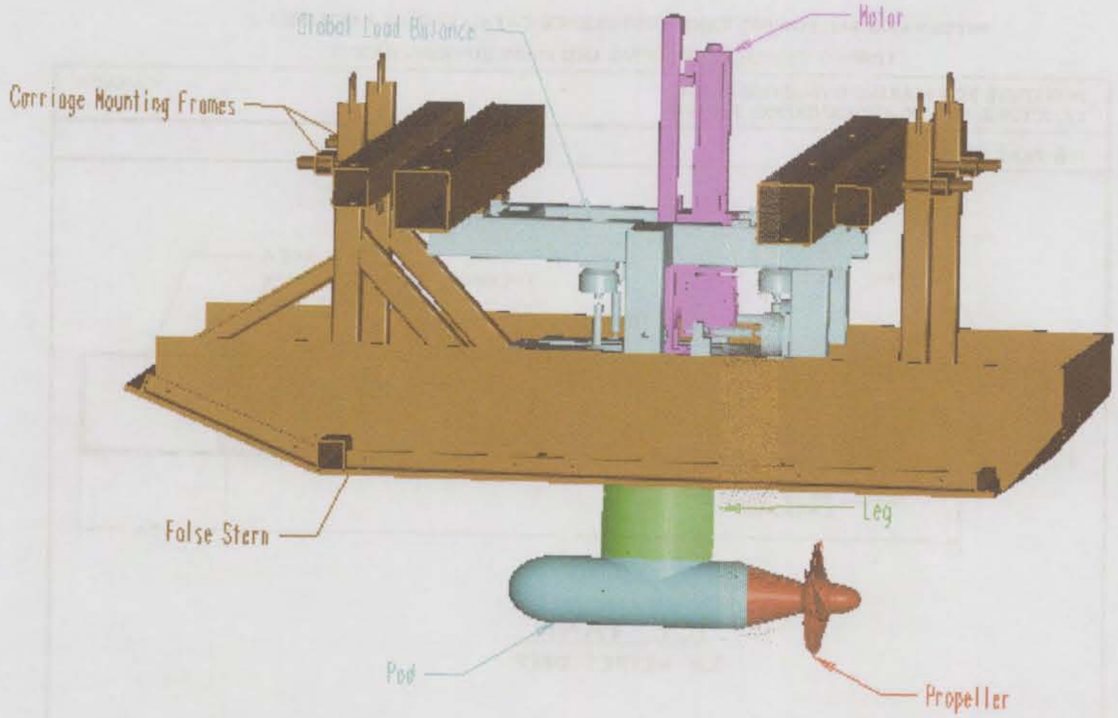


Figure 3. General Arragement.

The false stern is supported independently of the pod, allowing the false stern to be raised and lowered to vary the distance between the propeller and the stern. The pod supports and the false stern supports are both moved up and down together by the Ice Tank Carriage measuring beams. This movement is used to vary the draft of the whole apparatus.

Shown between the carriage mounting frames and the pod is a global load balance. This balance supported the pod and measured the loads that the leg, pod and propeller experienced as a whole in six degrees of freedom. A slip seal was provided between the leg and the false stern so that the propeller would not suck air down through the joint. This slip seal did not support the leg and thus did not interfere with the force measurements from the global load balance.

The live load plate of the global load balance supported the pod, leg and pod drive refer to Figure 5. This live plate was fitted with a rotary bearing to allow the pod as a unit to be yawed at any angle from dead ahead to dead astern. A chain and sprocket drive was provided to turn the pod in yaw.

A vertically mounted motor provided the power for the propeller. The motor was fitted with a planetary gear reduction and a bevel drive gearbox. The output shaft of the bevel gear box was fitted with a cogged pulley and belt. This belt drive ran down through the leg to a lay shaft in the pod. The power was then transferred onto the propeller shaft through a bellows coupling.

Two hollow, cylindrical, six-component load cells supported the propeller shaft through bearings. These two load cells measured the reactions that were required to support the propeller shaft at two locations in the pod, see Figure 4 below.

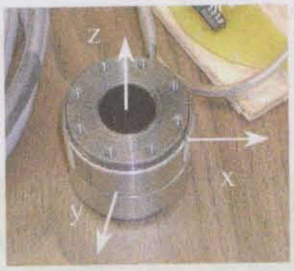


Figure 4. 6 Component AMTI load cell.

The propeller shaft was fitted with a necked down section immediately before entering the propeller hub. This necked down section was fitted with strain gages to measure the propeller torque.

The propeller was designed with 4 removable blades and a diameter of 0.3m. The blades were capable of being set for either push or pull mode. The hub of the propeller was fitted with a six-component load cell to measure the loads experienced by an individual blade.

The load measurement electrical signals from the blade balance in the propeller hub and the strain gauged section of the propeller shaft were pre amplified and then taken off the shaft by a set of slip rings. These slip rings and signal conditioning hardware were located in the pod body between the leg and the propeller hub.

3 CALIBRATION

For an explanation of the calibration procedure and it's implementation refer to the report, Ice Loading On Podded Propeller Systems: Calibration And Notes, Quinton, April 04, LM-2004-05.

4 TEST PROGRAM

4.1 Set-up Procedures

Before a test program was started, a series of X/Y pulls were conducted with the carriage stationary, and with the APP unit in the air. Cables were attached to the APP strut horizontally in the X/Y directions through inline load cells, refer to figure 4. Then 5Kg masses were applied sequentially to a total of 35Kg and removed first on the Y and then the X load cell, after which, a total load of 20Kg was applied to the X load cell and the Y was loaded up and down sequentially again. This provided a means of checking that the Global dyno was operational and that the APP unit and strut were not in contact with the False bottom.

With the X/Y cables detached the shaft was turned over, positive direction for pusher, negative direction for tractor, from 0 to 10 rps. This was to conduct an Airfriction test and to run in the bearings before the test program started.

Then the test frame was lowered until the False bottom was in contact with the waters surface, removing the free surface from above the propeller. Then Bollard tests were conducted, in the forward operating condition, positive for pusher, negative for tractor mode. The first Bollard was carried out from 0-5,0 rps, the second Bollard from 0,6-10,0 rps

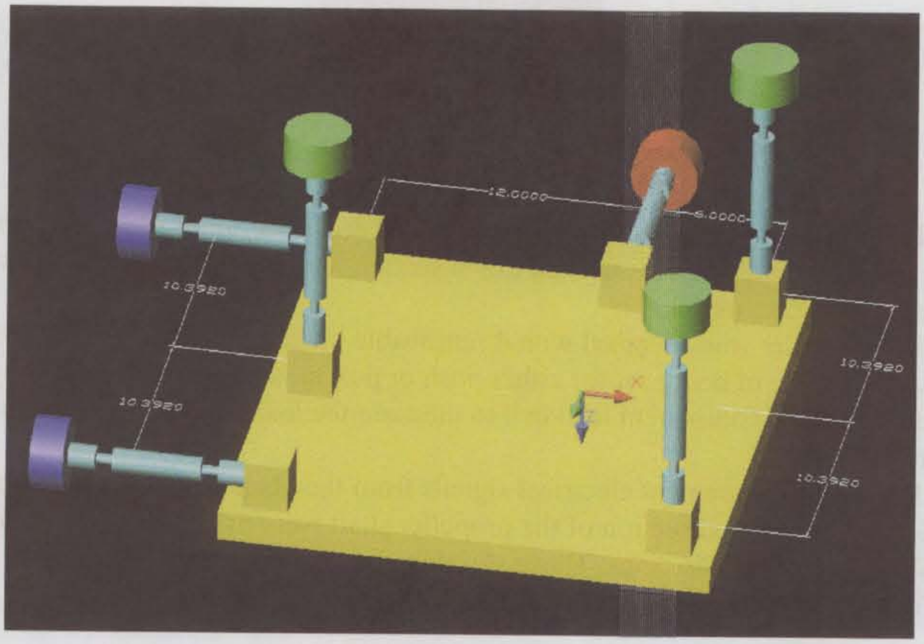


Figure 5. Global load cells and orientation of coordinate system, on live load plate.

Figure 6. For shaft dynos and direction of rotations..

A set-up procedure was also necessary for tests carried out in ice conditions. During the start of the test program it was found that the APP unit could sometimes come in contact with the ice sheets edge, pushing the sheet ahead, or down the tank. This resulted in excessive loading of the APP unit and was not characteristic of the conditions sought after. To prevent this occurrence, the ice sheet was pre-sawn along the test path, permitting the blocks in contact with the APP unit to break from the ice sheet. This procedure was also carried out in order that the ice sheet be conserved and used for multiple runs before resorting to running through pack ice conditions.

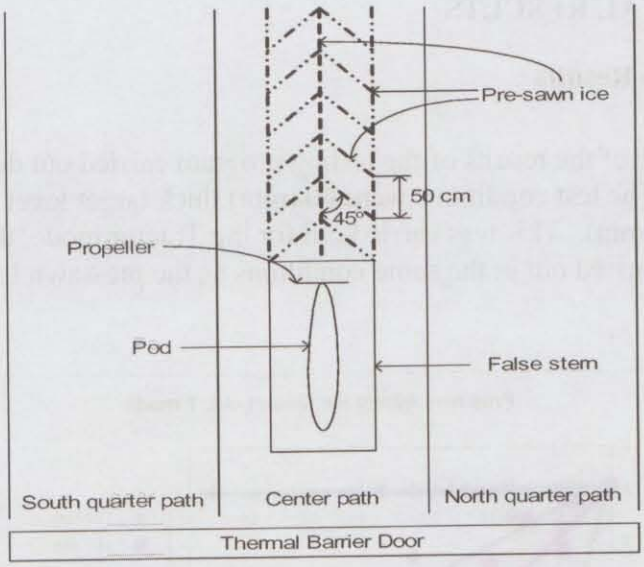


Figure 7. Pre-sawn ice and arrangements, for Tractor mode.

4.2 Test Matrix

The test matrix was designed to investigate the ice milling loads, ice contact and non-contact loads experienced by the blades as well as ice contact and non-contact loads experienced by the APP unit. The range of loading conditions investigated included variations in advance coefficient, depth of cut, ice sheet thickness and flexural strength, tractor and pusher mode and azimuth angle.

Pod Mode	Tractor mode, Pusher mode
Carriage Speed	0, 0.2, 0.5, 0.8 (m/s)
Propeller RPS	5, 7, 10 (Hz)
Target Depth of Cut	15, 35 (mm)
Azimuthing Angle (P mode)	0, 30, 60, 90, 120 (degree)
Azimuthing Angle (T mode)	180, 150, 120, 90, 60 (degree)
Ice Condition	Pre-sawn level ice, Pack ice, Open water
Target Ice Thickness/ Target Flexural Strength	60, 80 (mm)/ 60, 80 (kpa)

Table 1 Test matrix

5 EXPERIMENTAL RESULTS

5.1 Tractor Mode Results

Following are some of the results of the testing program carried out during the spring and summer of 2004. The test conditions were 60 (mm) thick target level ice, with a target depth of cut of 30 (mm). This was carried out for the Tractor mode, the pack ice and opens cases were carried out in the same conditions as the pre-sawn level ice. See Figures below.

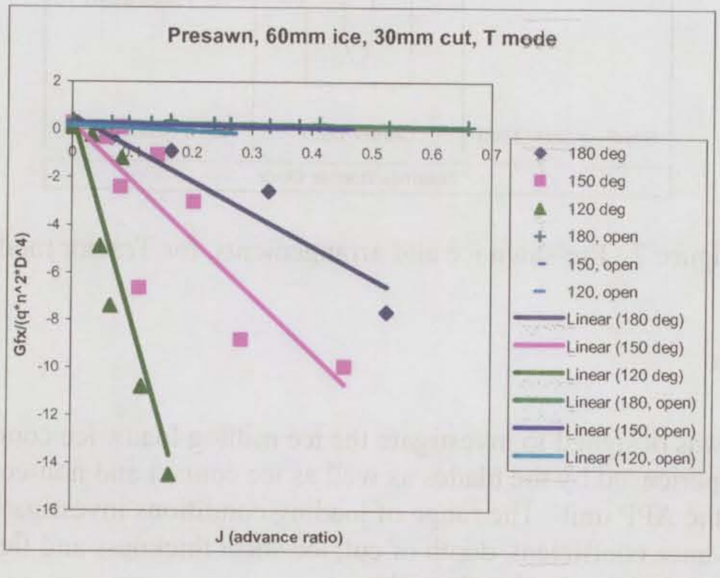


Figure 8. Global Fx, for Pre-sawn

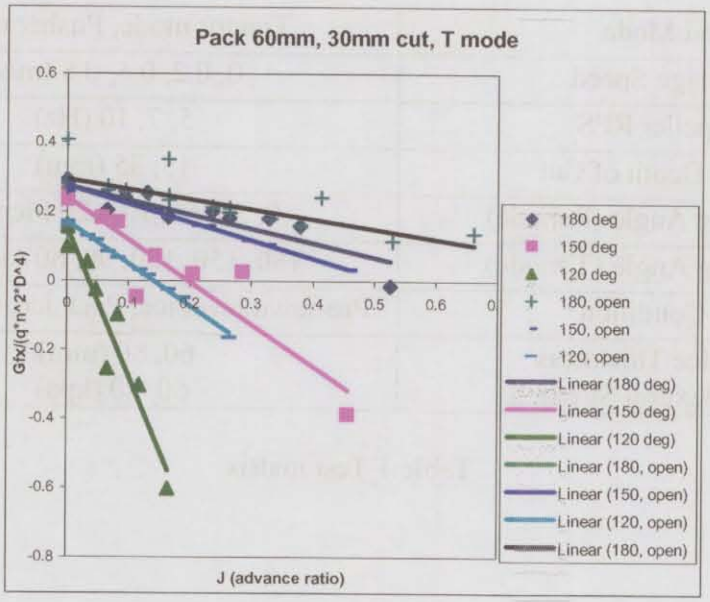


Figure 9. Global Fx, for Pack

It is apparent from Figure 8 and 9, that the overall resistance of the Pod is greatest in the Pre-sawn level ice condition, and it is a minimum in the Open water condition. The Pack ice condition experiences loads greater than the Open water, but only marginally. There is also a strong relationship between the Global Fx loads and the azimuth angle of the Pod.

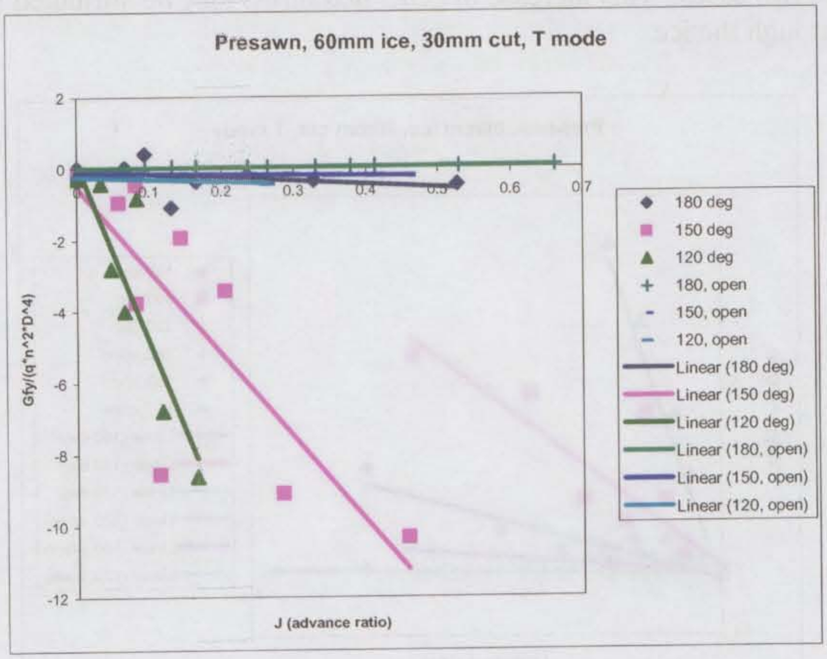


Figure 10. Global Fy, for Pre-sawn

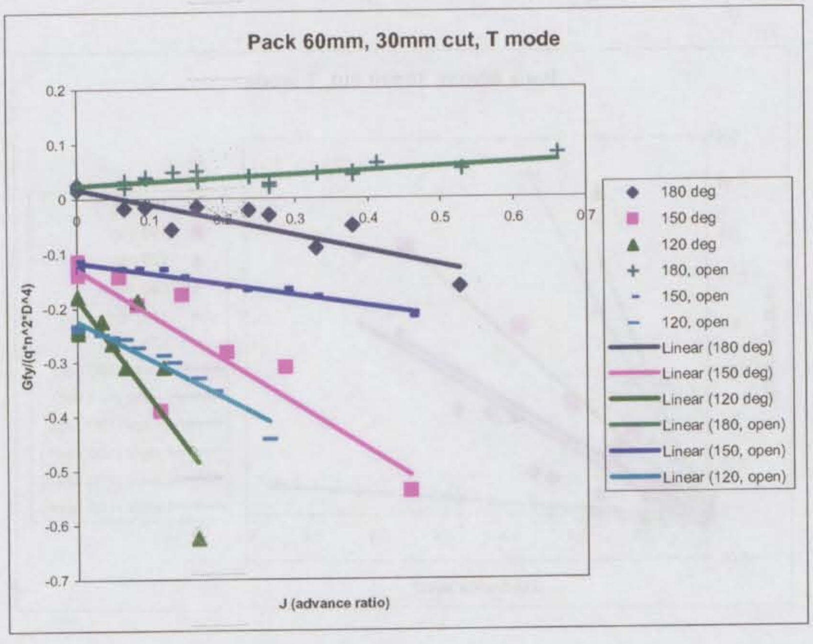


Figure 11. Global Fy, for Pack ice

The Global Fy loads also show a strong relationship with azimuth angle as discussed above, see Figure 10 and 11. This is to be expected as the azimuth angle increases the thrust generated by the Pod is shared by the Global Fx and Fy load cells. Further, a marked difference exists between the loads experienced during the Pre-sawn and the Pack ice tests. This may be attributed to an increase in thrust generated, as shown in the plots of KT for the two cases. This increase in generated thrust may be attributed to the effect of milling through the ice.

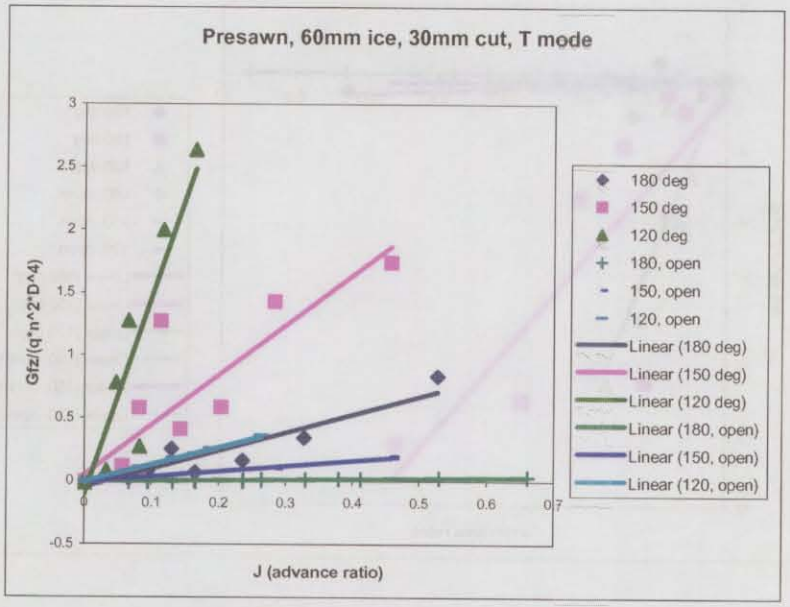


Figure 12. Global Fz, for Pre-sawn

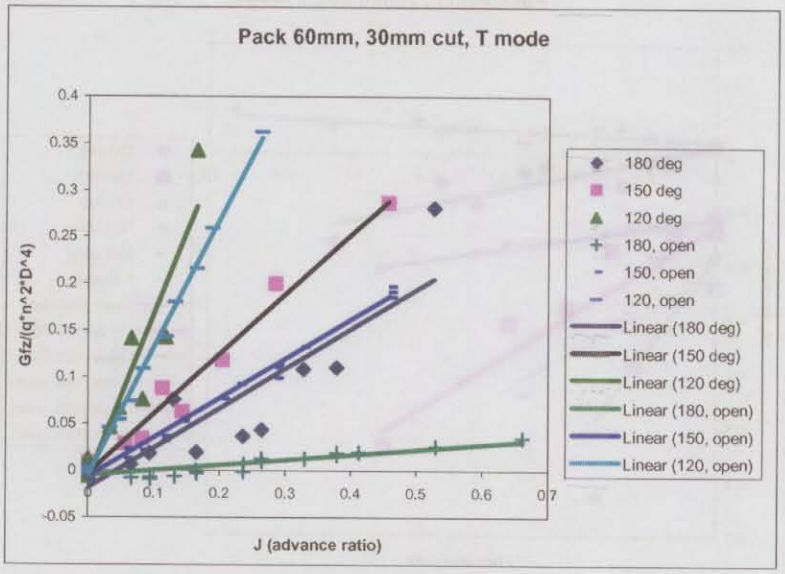


Figure 13. Global Fz, for Pack ice

Above in Figure 12 and 13, of note is the very close resemblence in the loads between the Open water scenario and the Pack ice scenario. However a marked increase in load in the Pack ice condition is present and may be due to the greater overall resistance of the Pod, and the resultant generated Global moment about the Y axis. In Figure 12 it may be seen again a marked increase in experienced loads over the Pack ice condition. This may again be the result of a greater generated moment as a result of increased resistance in the X direction. However a further possibility may be a Blockage effect due to the freshly milled ice being washed by the Propeller wake into the region above the Pod where the strut joins the Pod. The resultant blocked flow may result in an increased flow under the Pod, with a resultant pressure drop, therefore generating an increased net downward force on the Pod.

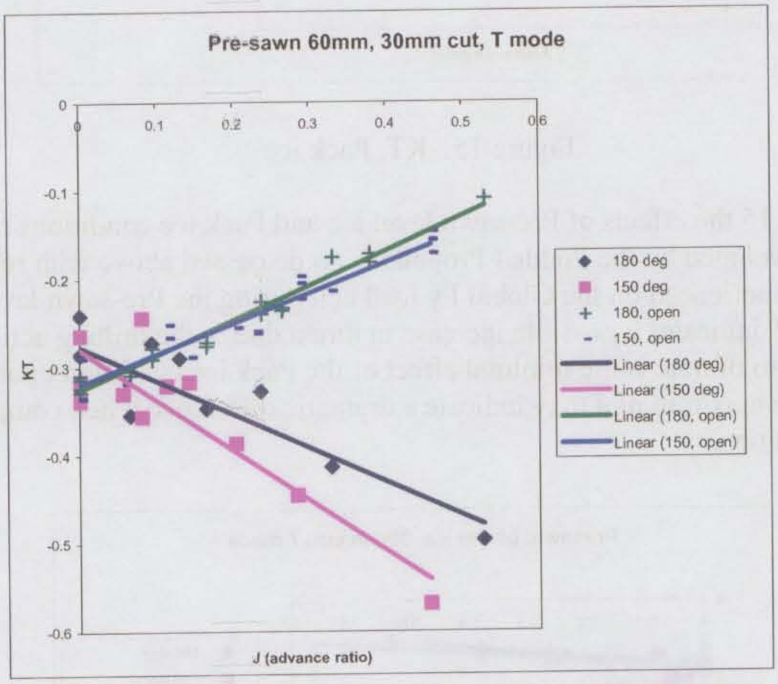


Figure 14. KT, Pre-sawn

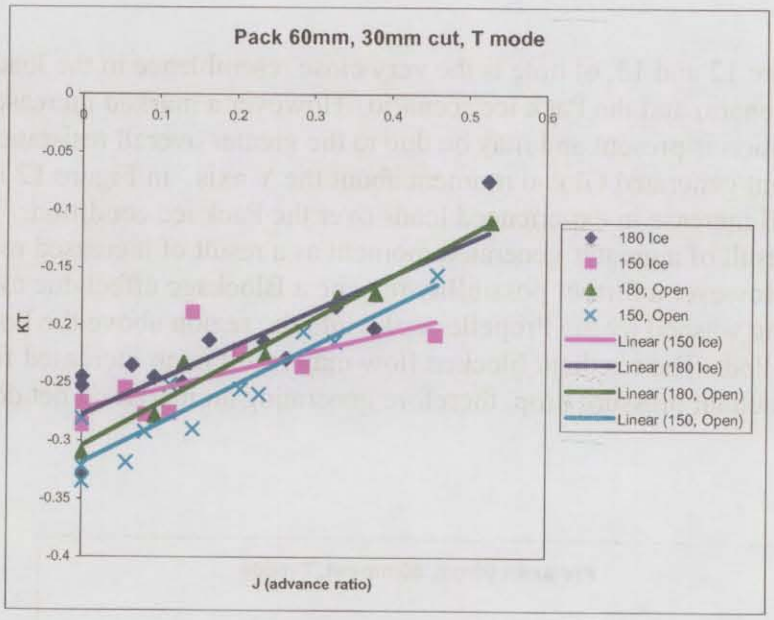


Figure 15. KT, Pack ice

In Figure 14 and 15 the effects of Pre-sawn level ice and Pack ice conditions may be seen on the Thrust developed by the Podded Propeller. As discussed above with regards to an increased load experienced on the Global Fy load cell during the Pre-sawn level ice tests, an increase in KT indicates a possible increase in thrust due to the milling action through the ice sheet. Also of note is the minimal effect of the Pack ice condition upon the mean thrust, however a max/min plot may indicate a dramatic difference when compared to the Open water condition.

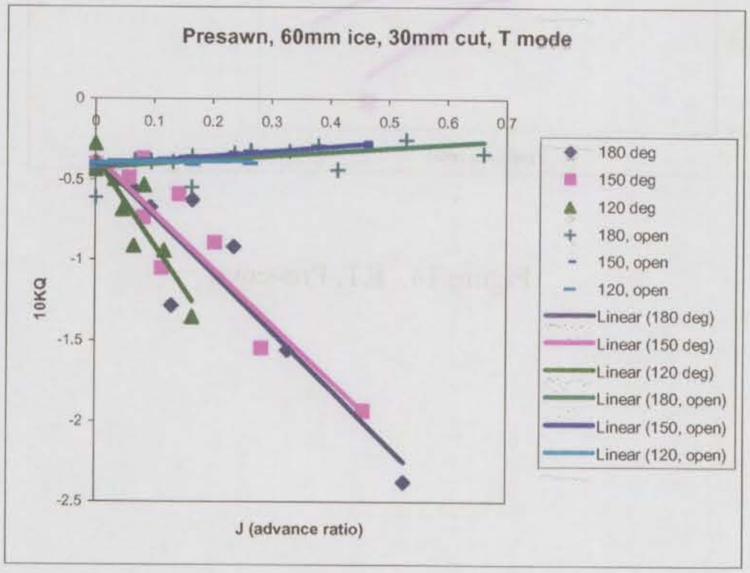


Figure 16. 10KQ, Pre-sawn ice

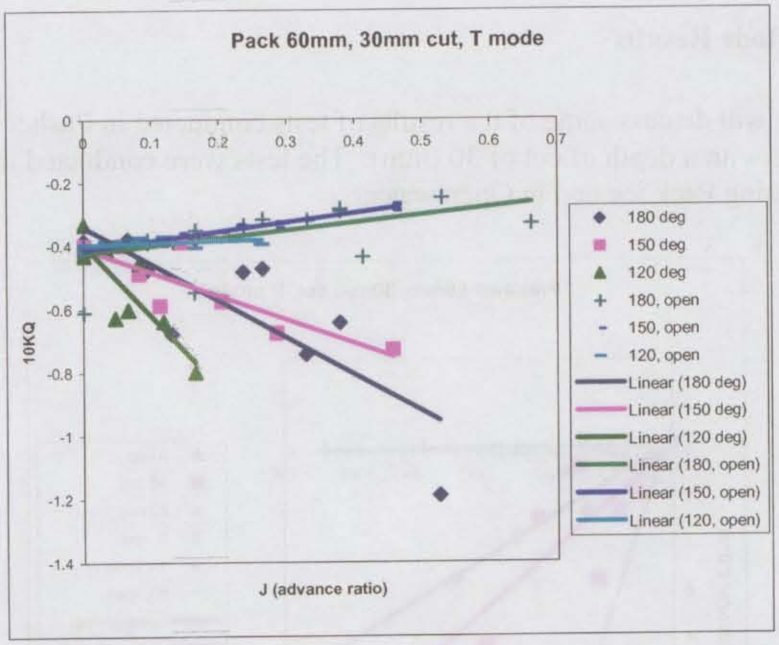


Figure 17. 10KQ, Pack ice

In reference to Figure 16 and 17 above, an increase in torque developed, with increasing azimuth angle and increasing advance ratio, is clearly indicative of action between the propeller and ice. Further, as may be seen above, the overall torque experienced during operation in Pack ice conditions is about half that experienced during operation in Pre-sawn level ice conditions.

5.2 Pusher Mode Results

The following will discuss some of the results of tests conducted in Pusher mode, in 60 (mm) thick ice with a depth of cut of 30 (mm). The tests were conducted in Pre-sawn level ice, resulting Pack ice and in Open water.

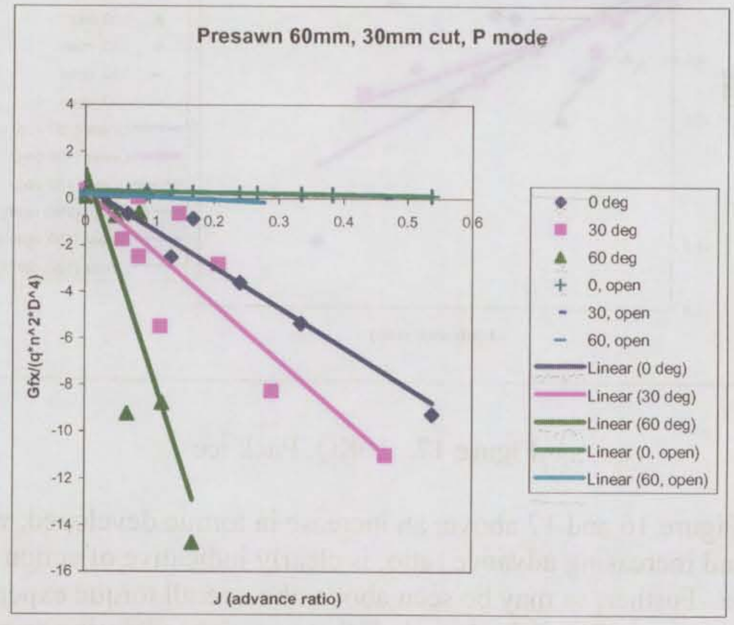


Figure 18. Global Fx, Pre-sawn ice

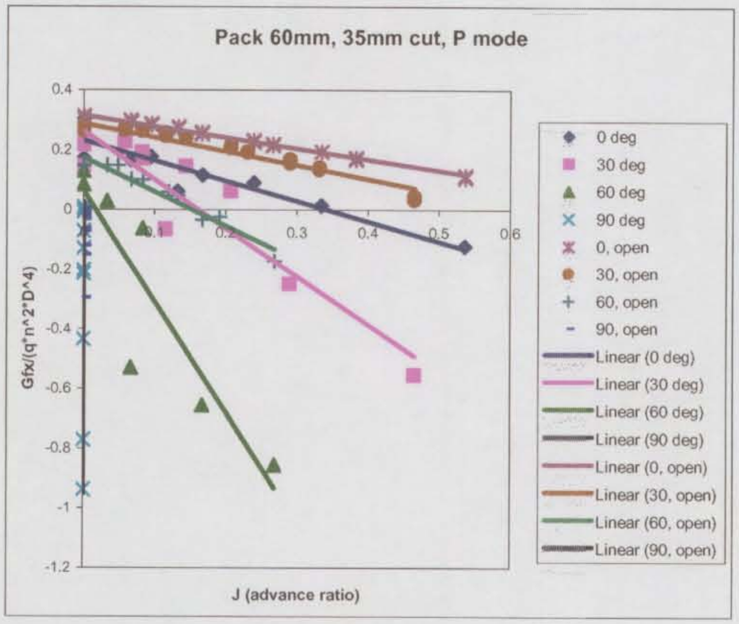


Figure 19. Global Fx, Pack ice

The trend of increasing load with increasing advance ratio and increasing azimuth angle, as noted previously for the Tractor condition, applies here to the Global Fx load for the Pusher condition. As before, the loads are greatest for the Pre-sawn level ice condition, and the Pack ice condition is marginally greater then the Open water condition. Of note however is that the Global Fx loads are greater in the Pre-sawn level ice condition for the Pusher mode, than for the Tractor mode. This may be a result of the undisturbed ice sheet coming into contact with the Pod strut, at which point it is broken up and passes into the disk area. It should also be noted that the loads for the Global Fx direction for both Tractor and Pusher mode in Pack ice conditions are similar.

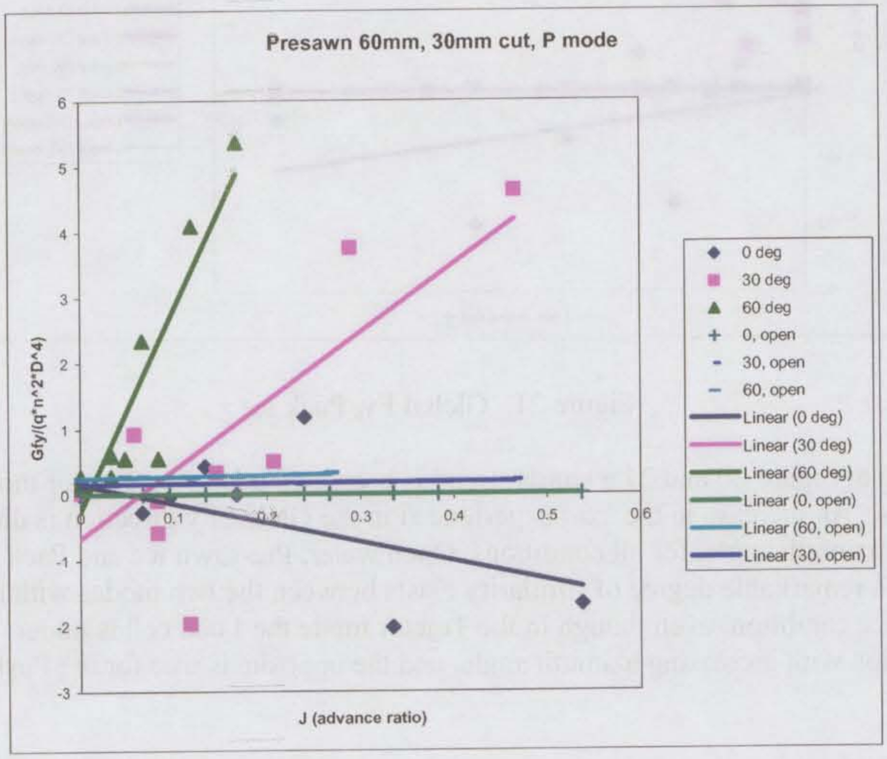


Figure 20. Global Fy, Pre-sawn ice

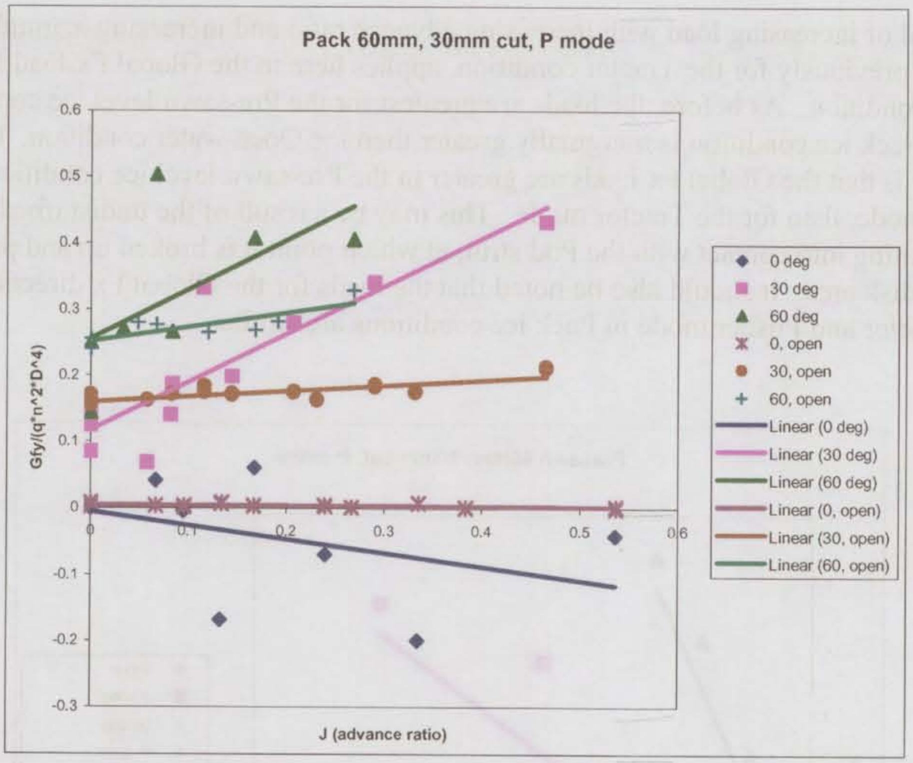


Figure 21. Global Fy, Pack ice

In looking at Figure 20 and 21 a similar trend is presented as for the Tractor mode conditions. An increase in the load experienced in the Global Fy direction is directly related to azimuth angle, for all conditions, Open water, Pre-sawn ice and Pack ice. However a remarkable degree of similarity exists between the two modes with regards to the Pack ice condition, even though in the Tractor mode the Load cell is under compression with increasing azimuth angle, and the opposite is true for the Pusher mode.

With regards to Figure 24 and 25, the results of the Pusher mode in Pre-sawn level ice and Pack ice primarily indicate high variability in the mean value of Thrust developed. This is of interest, as in the Tractor mode a marked increase in thrust developed occurred in the Pre-sawn level ice tests.

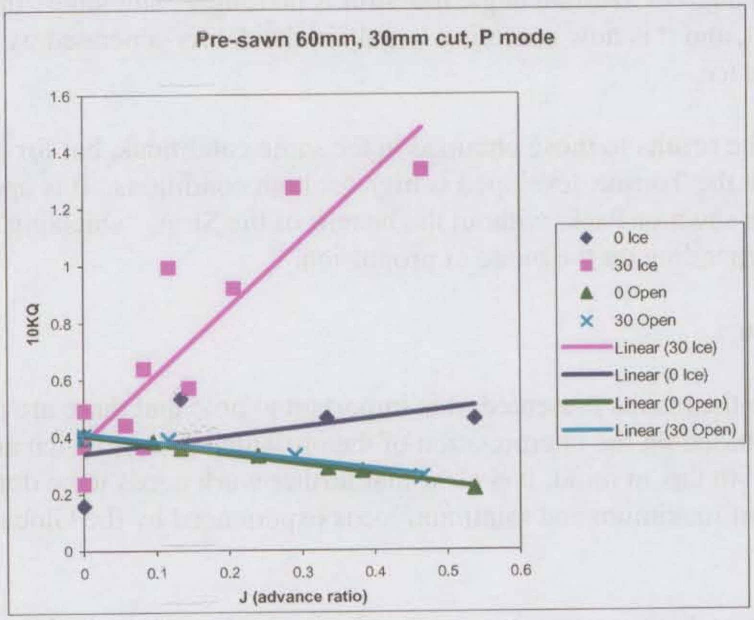


Figure 26. 10KQ, Pre-sawn ice

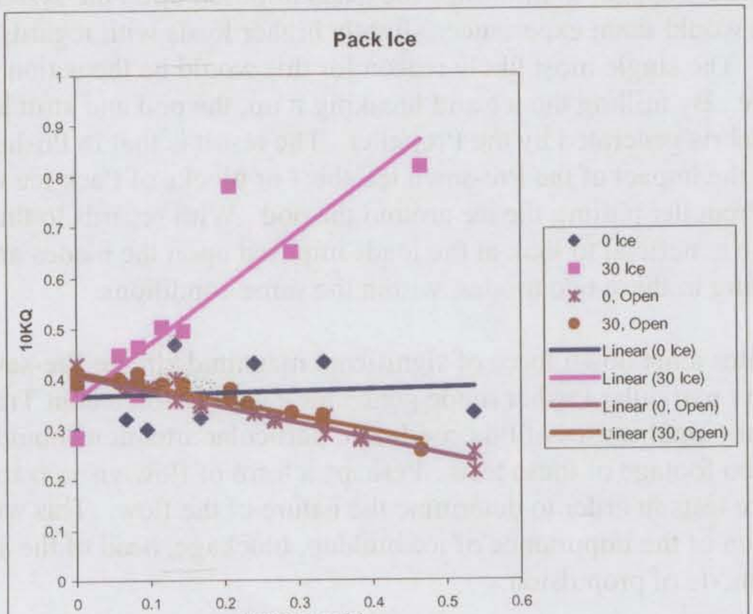


Figure 27. 10KQ, Pack ice

The developed torque in Pusher mode, for both the Pre-sawn level ice and Pack ice conditions, at 0 degrees azimuth angle, show similar results. This could be a result of the Strut clearing the way for the Propeller in the Pre-sawn level ice tests, therefore the Propeller would be operating in conditions resembling those of the Pack ice conditions. Further substantiating this, is the difference in these two results at an azimuth angle of 30 degrees. At 30 degrees azimuth angle the Strut is no longer "shielding" the Propeller to the same extent, and it is now operating largely in the debris generated by the Strut breaking up the ice.

In comparing the results to those obtained in the same conditions, but for Tractor mode, one can see that the Torque developed is high for both conditions. It is operating directly into the ice, Pre-sawn or Pack, without the benefit of the Struts "shielding" effects at 0 or 180 degrees, depending on the mode of propulsion.

6 Conclusion

With regards to the results presented, it is important to note that these are preliminary results and are based on the interpretation of the presented graphs which are of mean values only. With this in mind, it is clear that further work needs to be done with regards to the analysis of maximum and minimum loads experienced by the Global Dynamometer.

However, some preliminary conclusions may be made about the role the strut, pod, and ice play within the context. Firstly, the mode of propulsion plays a significant role in determining the magnitude of the loads imposed upon the Global Dynamometer. The Tractor mode would appear to minimize the loads imposed upon the system, while Pusher mode it would seam experiences slightly higher loads with regards to the Global Dynamometer. The single most likely reason for this would be the action of the Propeller in Tractor mode. By milling the ice and breaking it up, the pod and strut have to contend with only the debris generated by the Propeller. The result is that in Pusher mode the strut must take the impact of the Pre-sawn ice sheet or blocks of Pack ice with little if any benefit of the Propeller pulling the ice around the pod. With regards to this milling action, it will be beneficial to look at the loads imposed upon the blades and shaft as a result of operating in these two modes, within the same conditions.

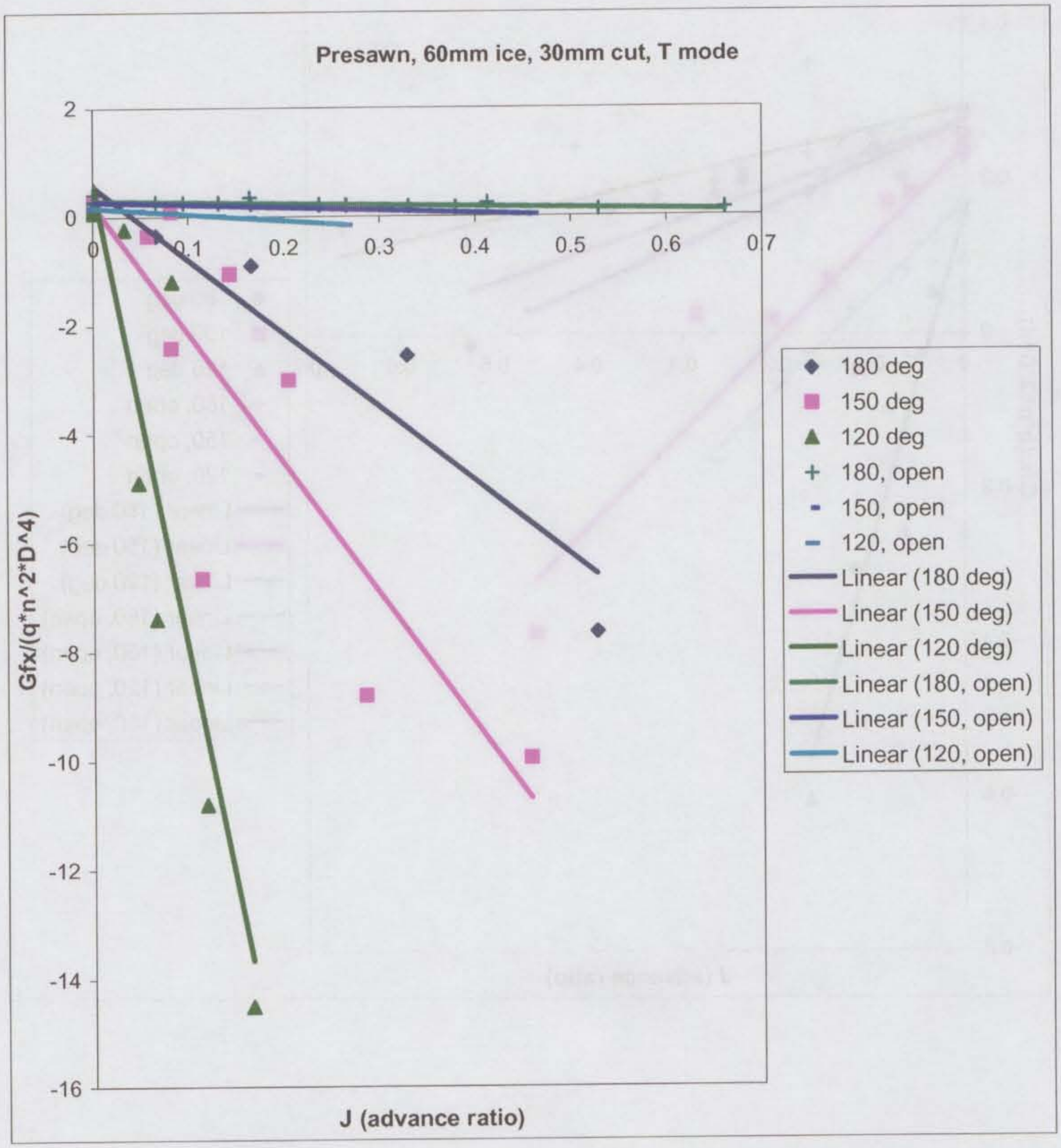
The pod generates a net down force of significant magnitude in the Pre-sawn level ice condition, and in particular Pusher mode generates a greater force than Tractor. To determine the principal causes of this condition, particular attention should be paid to the underwater video footage of these tests. Perhaps a form of flow visualization could be applied to future tests in order to determine the nature of the flow. This would facilitate the determination of the importance of ice buildup, blockage, head of the strut, as it pertains to the mode of propulsion.

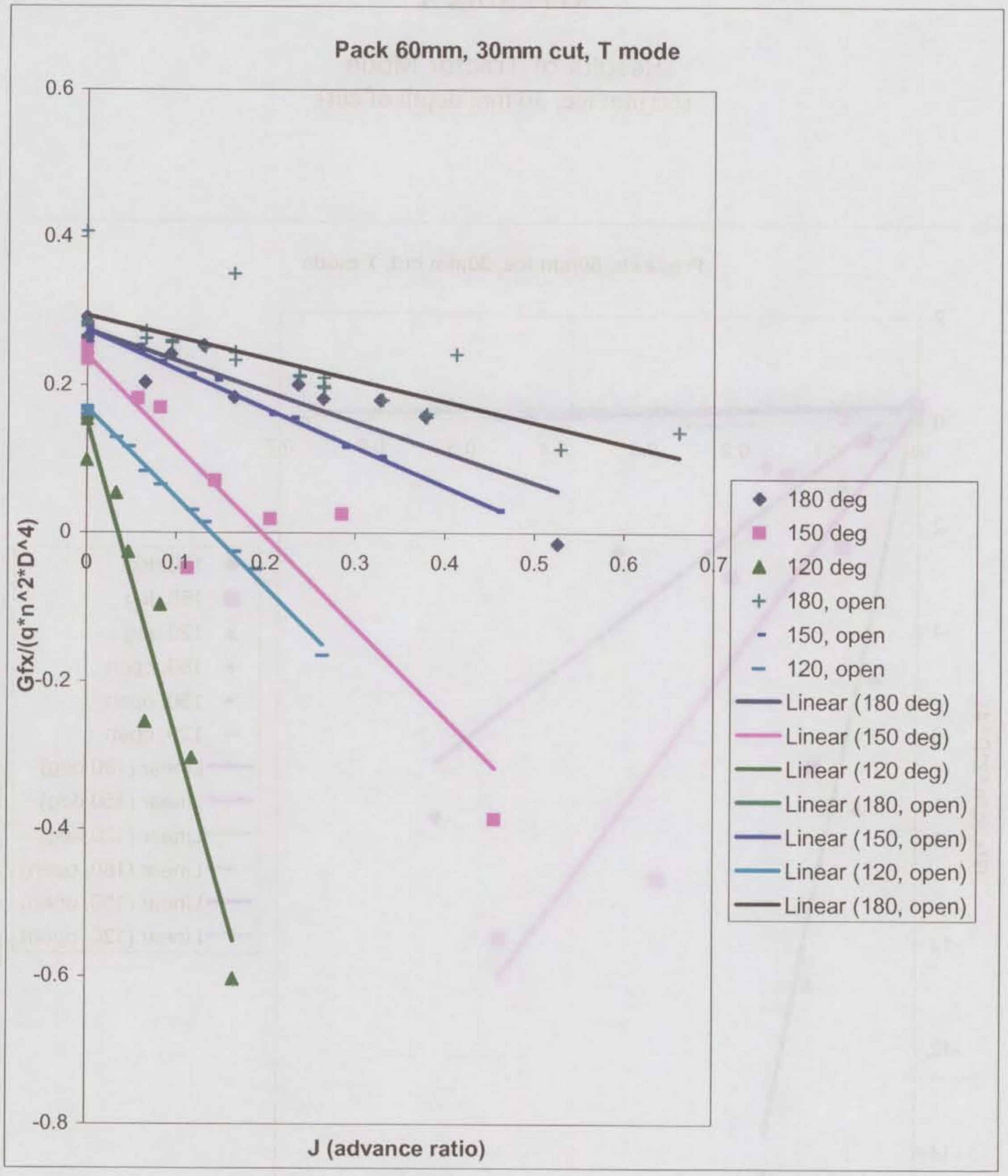
In closing, it may be stated that the mean loads experienced by an Azimuthing Podded Propulsor operating within a field dominated by ice are significantly higher than those imposed upon the system in equivalent open water conditions. Further, the mode of propulsion plays a key role in determining the magnitude of the ice loads experienced by the Global Dynamometer and in determining the magnitude of thrust and torque developed in ice conditions.

Extensive analysis of the results remains, in the form of investigating the maximum and minimum loads the Global Dynamometer is subjected to and in conducting error and uncertainty analysis. It would also seam that analysis of the Blade and Shaft Dynamometer loads recorded could be of significant importance in order to obtain a full understanding of the dynamics. With the knowledge of how Azimuthing Podded Propellers interact with ice, and to what degree the loads increase in these conditions, a method of assessing a Podded Propulsor design for its suitability to ice operating conditions may be made.

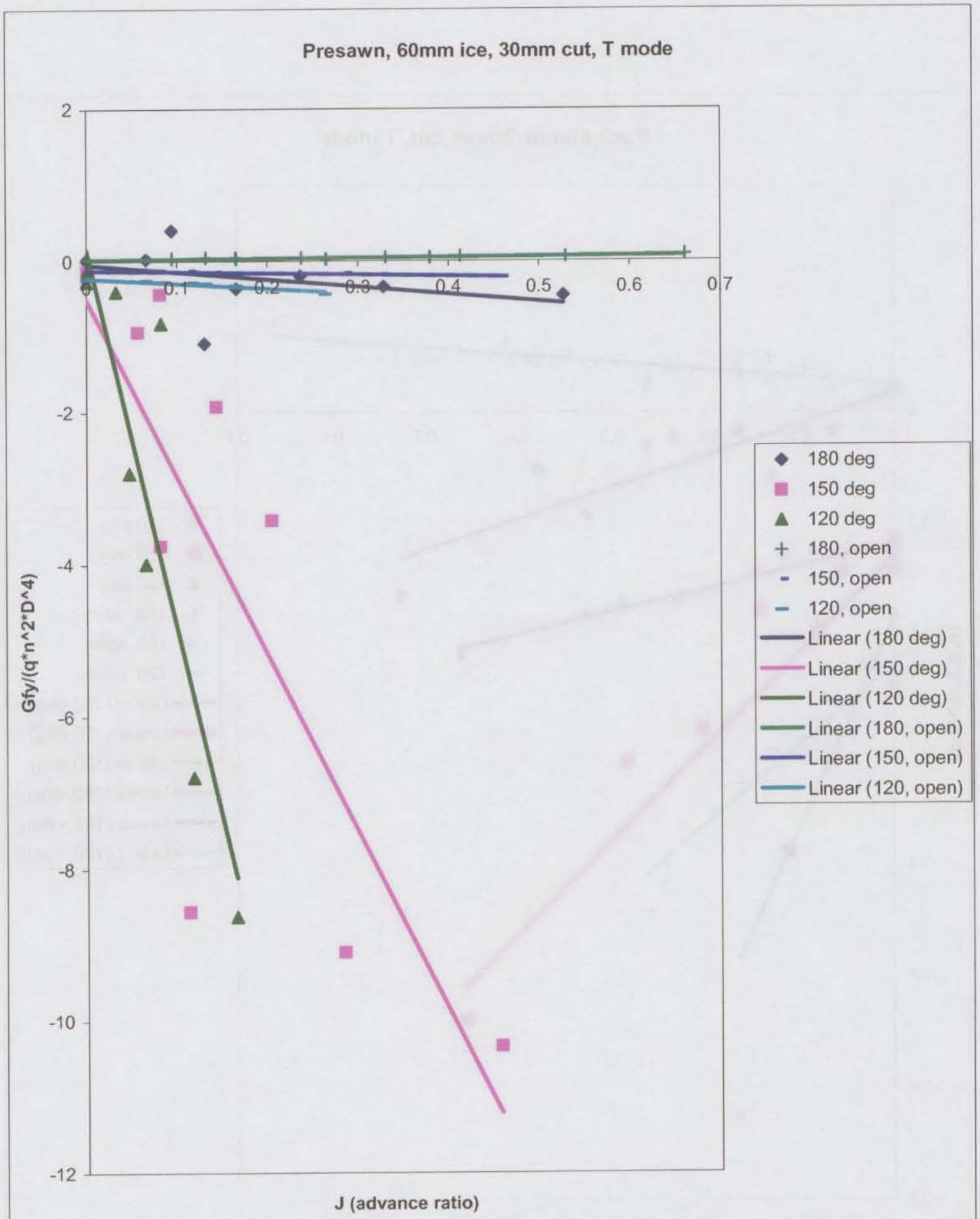
APPENDIX A

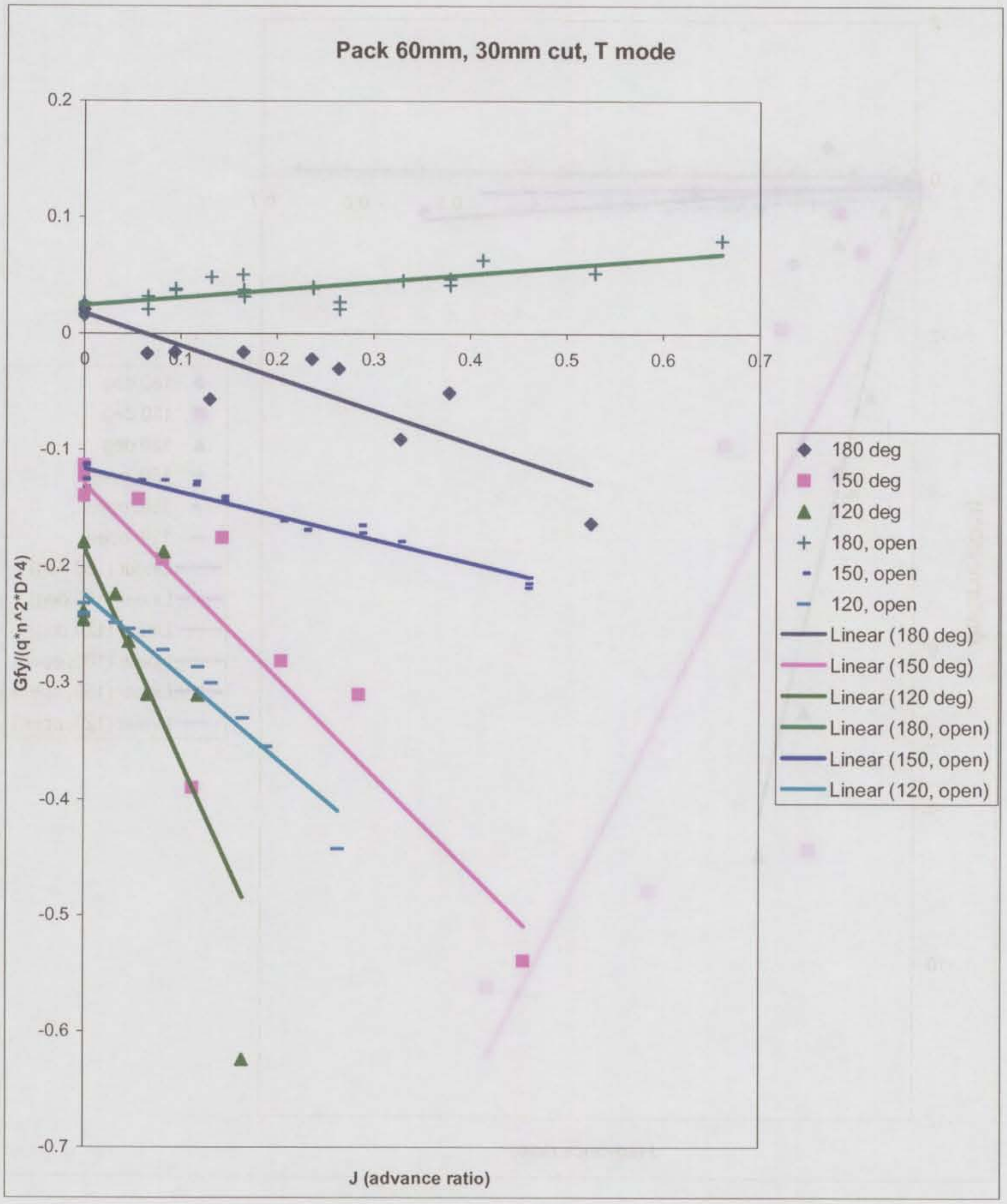
Results of Tractor Mode
(60 mm ice, 30 mm depth of cut)



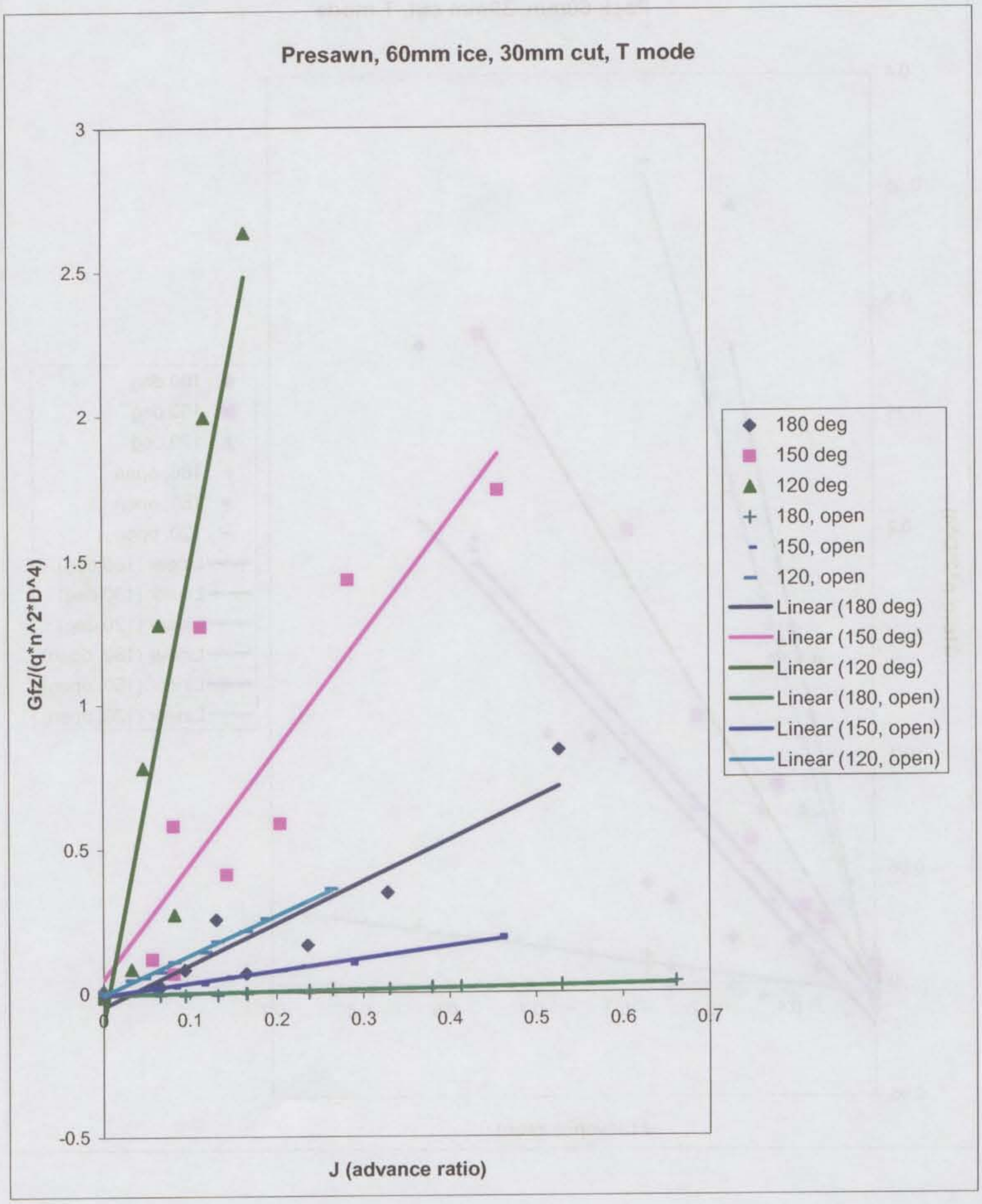


Pack 60mm, 30mm cut, T mode
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Gfx/(q*n^2*D^4)
J (advance ratio)
180 deg
150 deg
120 deg
180, open
150, open
120, open
Linear (180 deg)
Linear (150 deg)
Linear (120 deg)
Linear (180, open)
Linear (150, open)
Linear (120, open)
Linear (180, open)

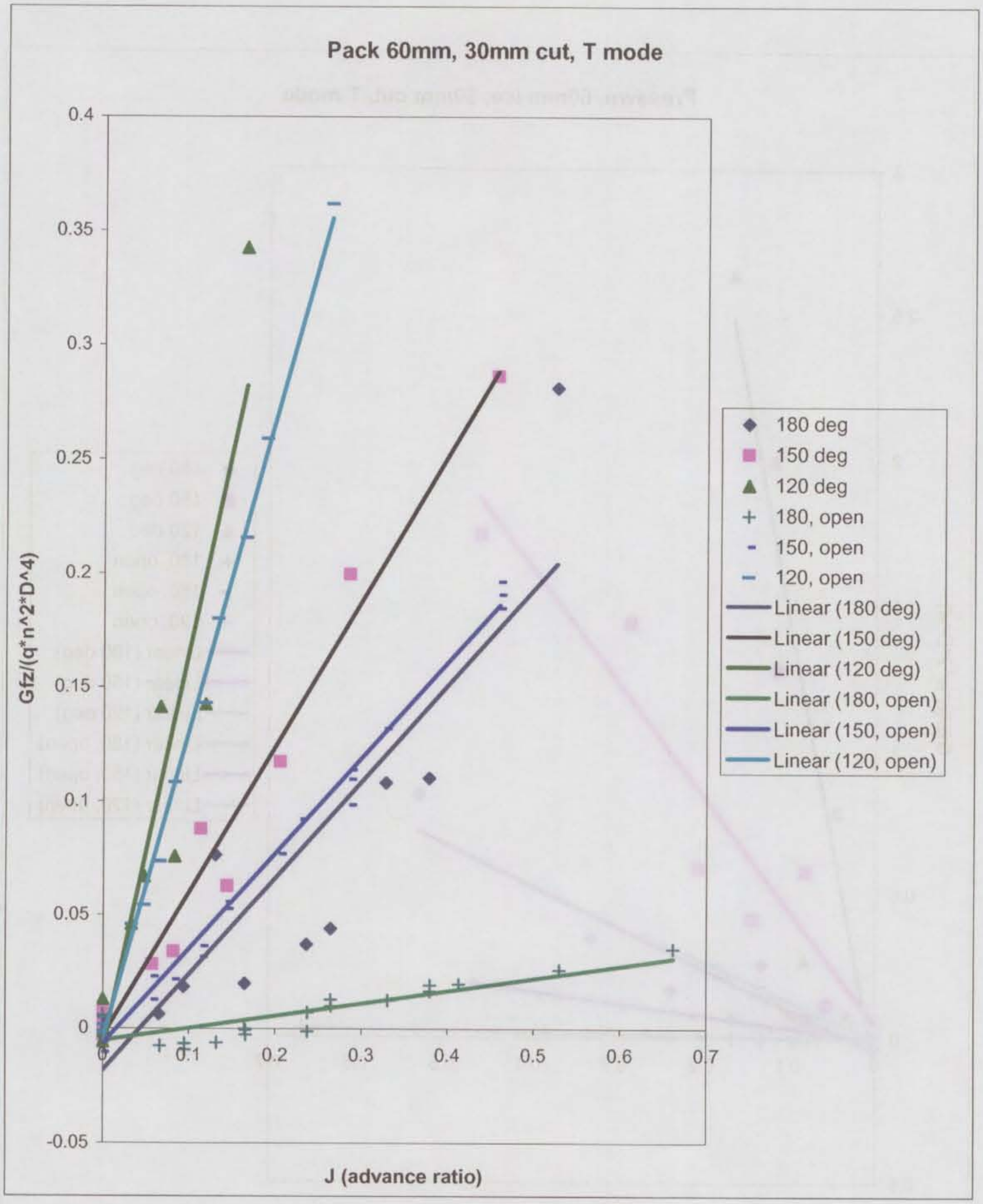

Presawn, 60mm ice, 30mm cut, T mode
Gfy/(q*n^2*D^4)
J (advance ratio)
2
0
-2
-4
-6
-8
-10
-12
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
180 deg
150 deg
120 deg
180, open
150, open
120, open
Linear (180 deg)
Linear (150 deg)
Linear (120 deg)
Linear (180, open)
Linear (150, open)
Linear (120, open)



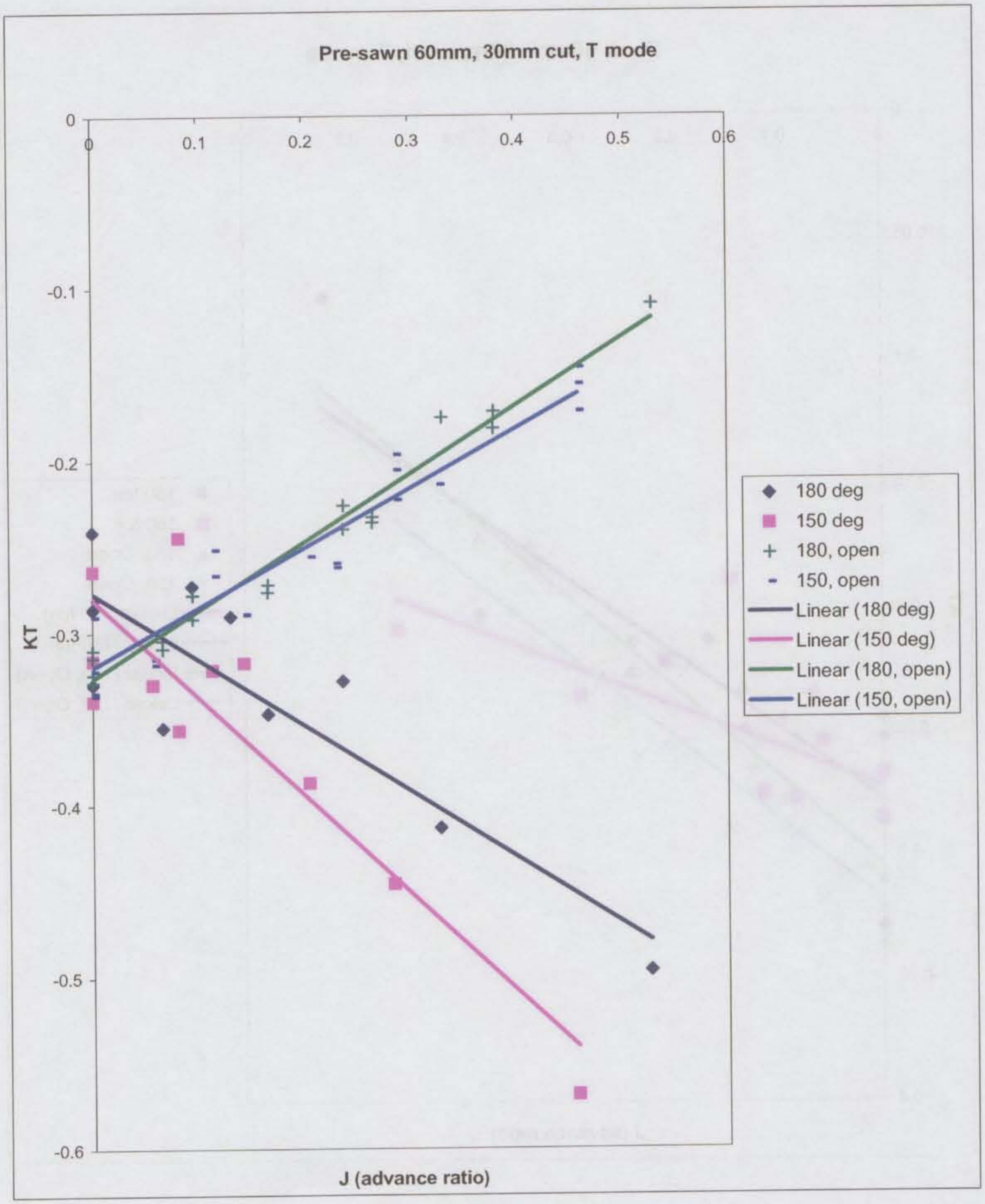
Pack 60mm, 30mm cut, T mode
Gfy/(q*n^2*D^4)
J (advance ratio)
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
180 deg
150 deg
120 deg
180, open
150, open
120, open
Linear (180 deg)
Linear (150 deg)
Linear (120 deg)
Linear (180, open)
Linear (150, open)
Linear (120, open)



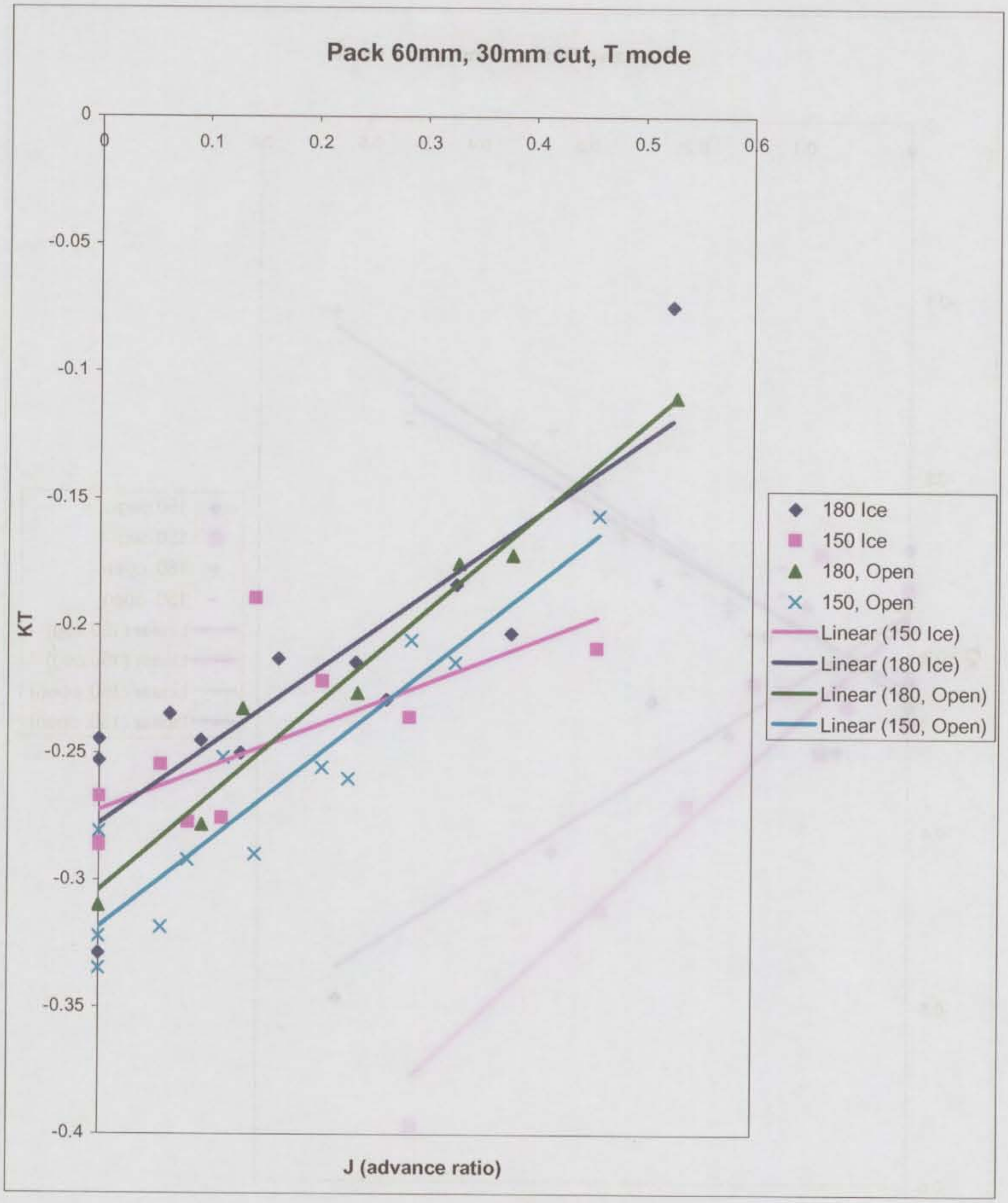
Presawn, 60mm ice, 30mm cut, T mode
Gfz/(q*n^2*D^4)
J (advance ratio)
3
2.5
2
1.5
1
0.5
0
-0.5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
180 deg
150 deg
120 deg
180, open
150, open
120, open
Linear (180 deg)
Linear (150 deg)
Linear (120 deg)
Linear (180, open)
Linear (150, open)
Linear (120, open)

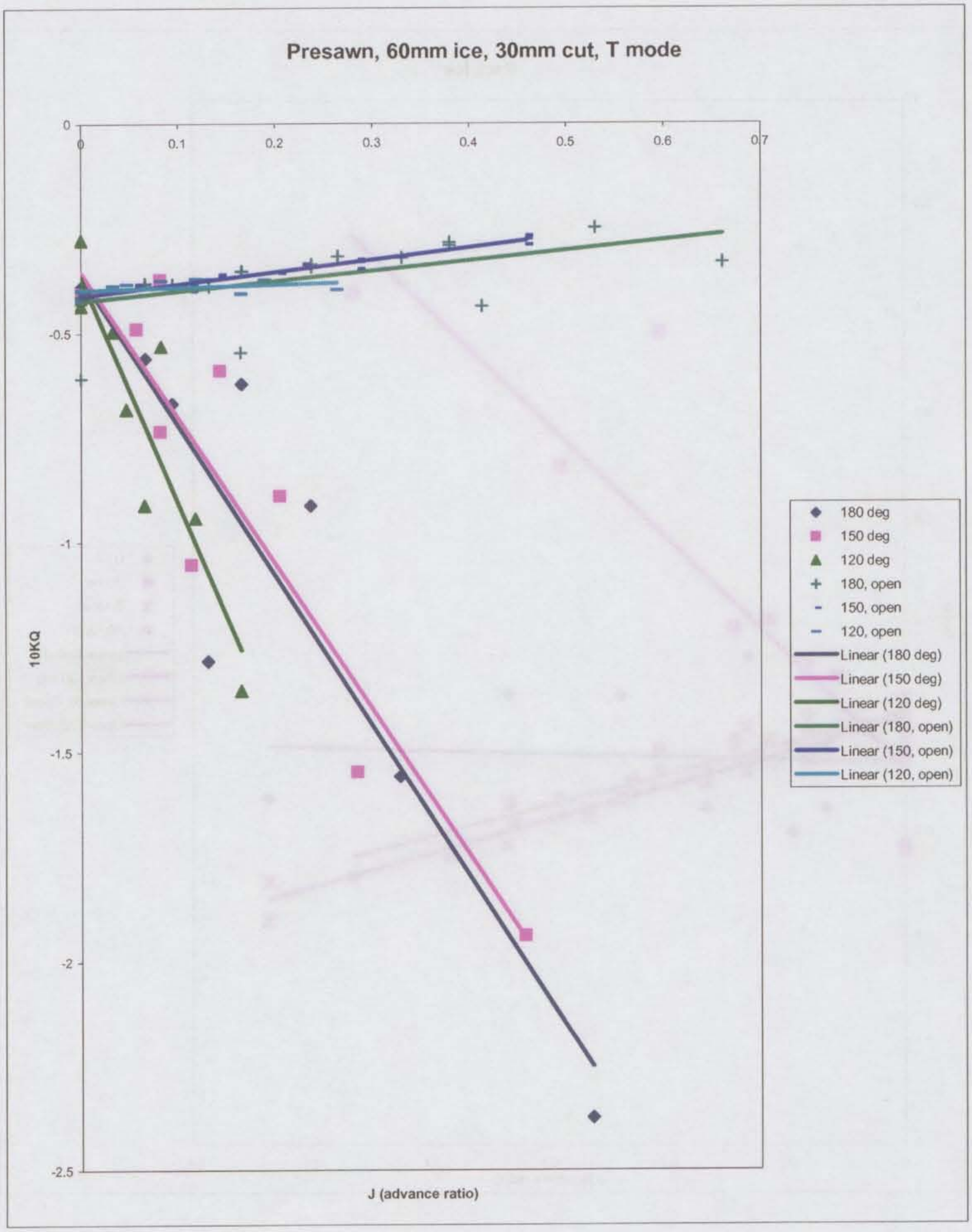


Pack 60mm, 30mm cut, T mode
Gfz/(q*n^2*D^4)
J (advance ratio)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
180 deg
150 deg
120 deg
180, open
150, open
120, open
Linear (180 deg)
Linear (150 deg)
Linear (120 deg)
Linear (180, open)
Linear (150, open)
Linear (120, open)

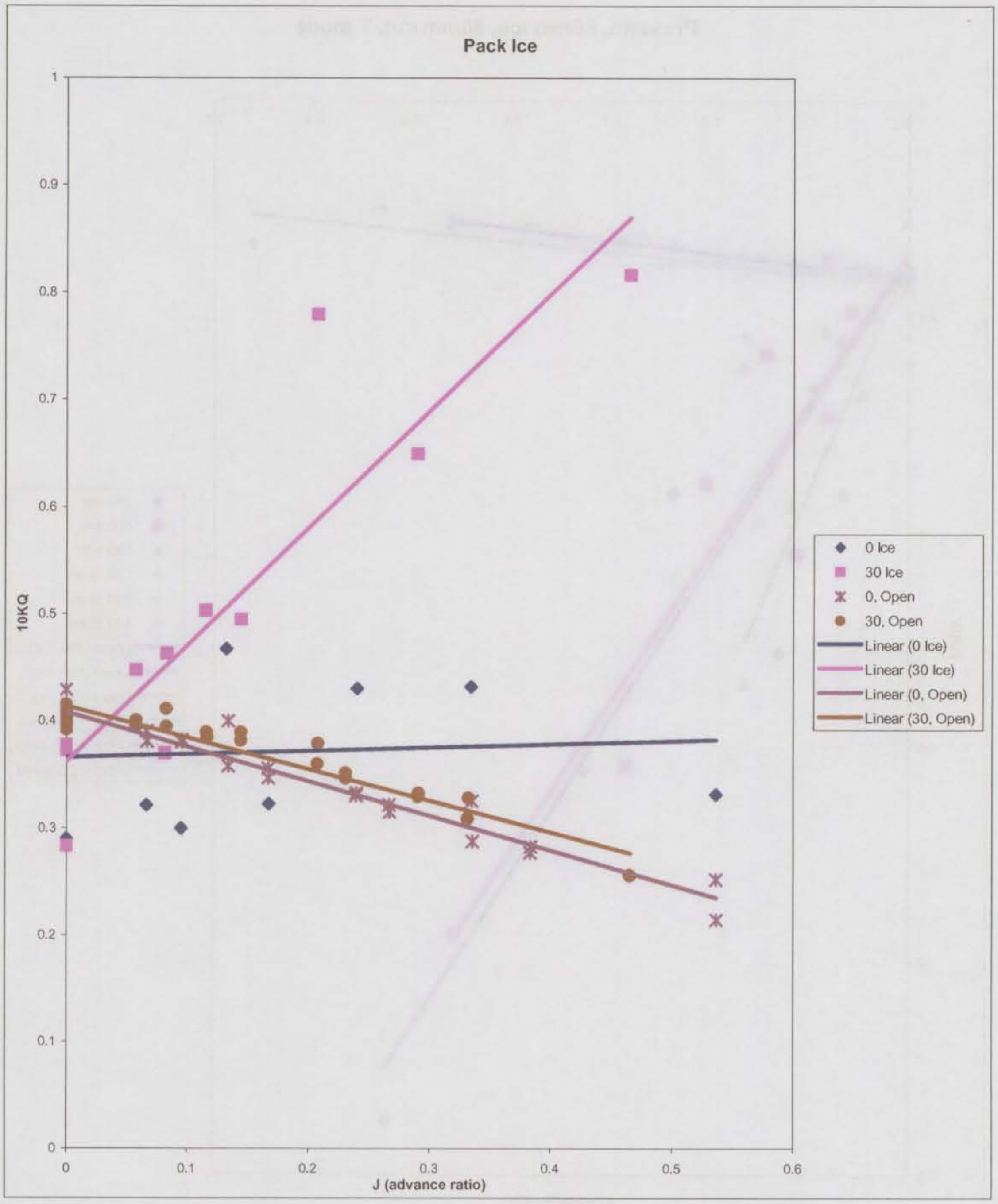


Pre-sawn 60mm, 30mm cut, T mode
0
0.1
0.2
0.3
0.4
0.5
0.6
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
KT
J (advance ratio)
180 deg
150 deg
180, open
150, open
Linear (180 deg)
Linear (150 deg)
Linear (180, open)
Linear (150, open)


Pack 60mm, 30mm cut, T mode
0
0.1
0.2
0.3
0.4
0.5
0.6
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-0.4
KT
J (advance ratio)
180 Ice
150 Ice
180, Open
150, Open
Linear (150 Ice)
Linear (180 Ice)
Linear (180, Open)
Linear (150, Open)

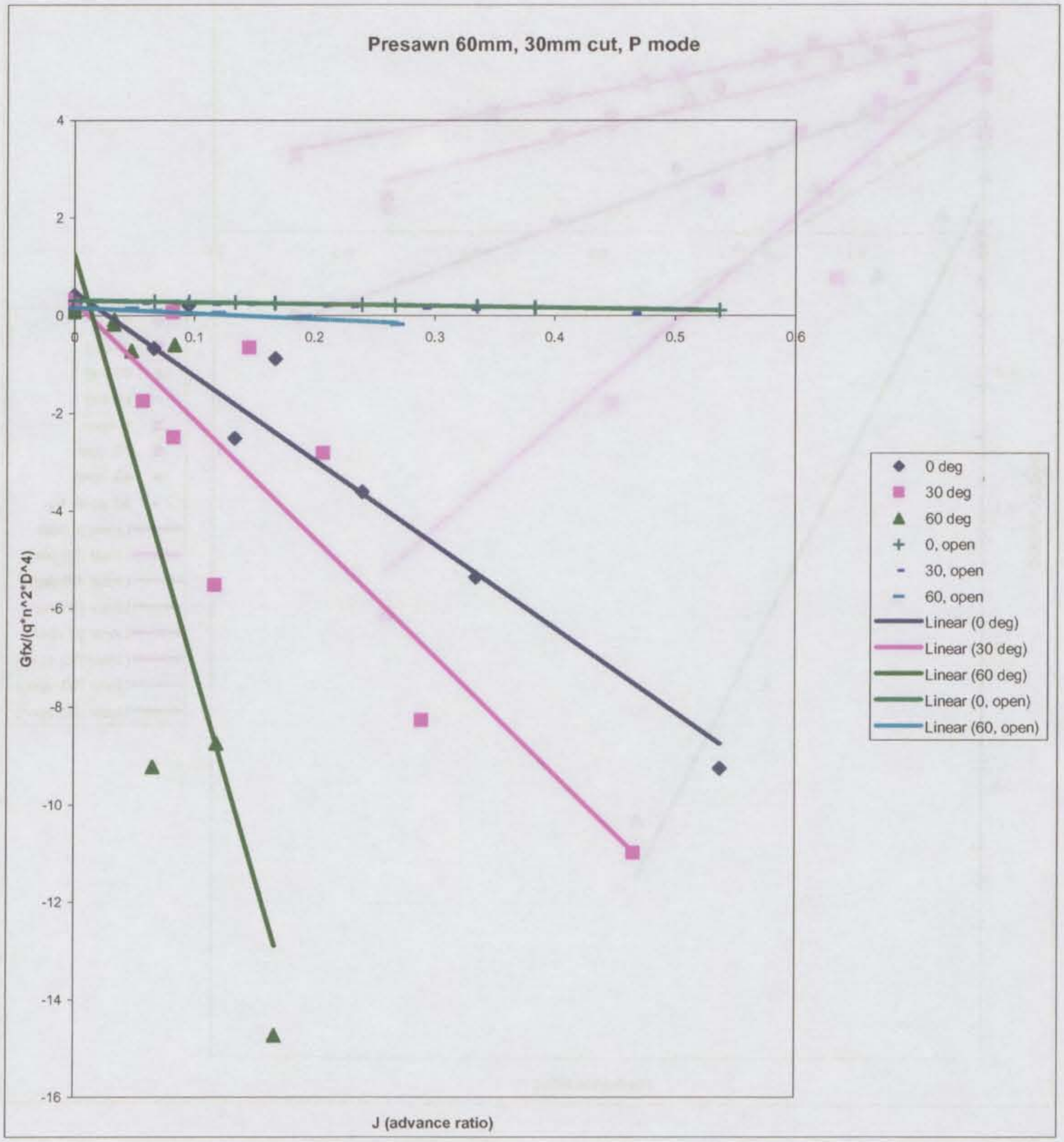


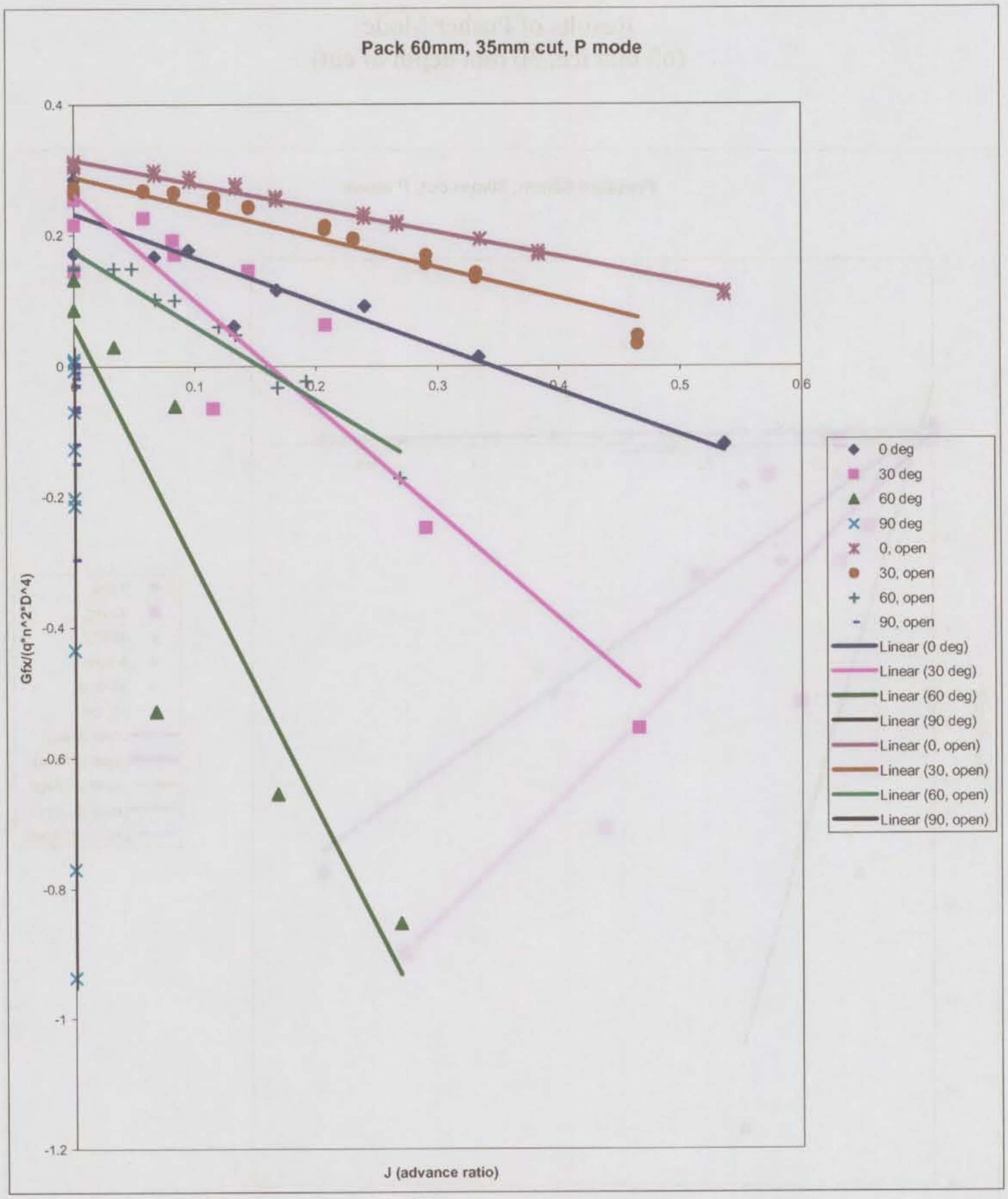
Presawn, 60mm ice, 30mm cut, T mode
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
-0.5
-1
-1.5
-2
-2.5
10KQ
J (advance ratio)
180 deg
150 deg
120 deg
180, open
150, open
120, open
Linear (180 deg)
Linear (150 deg)
Linear (120 deg)
Linear (180, open)
Linear (150, open)
Linear (120, open)

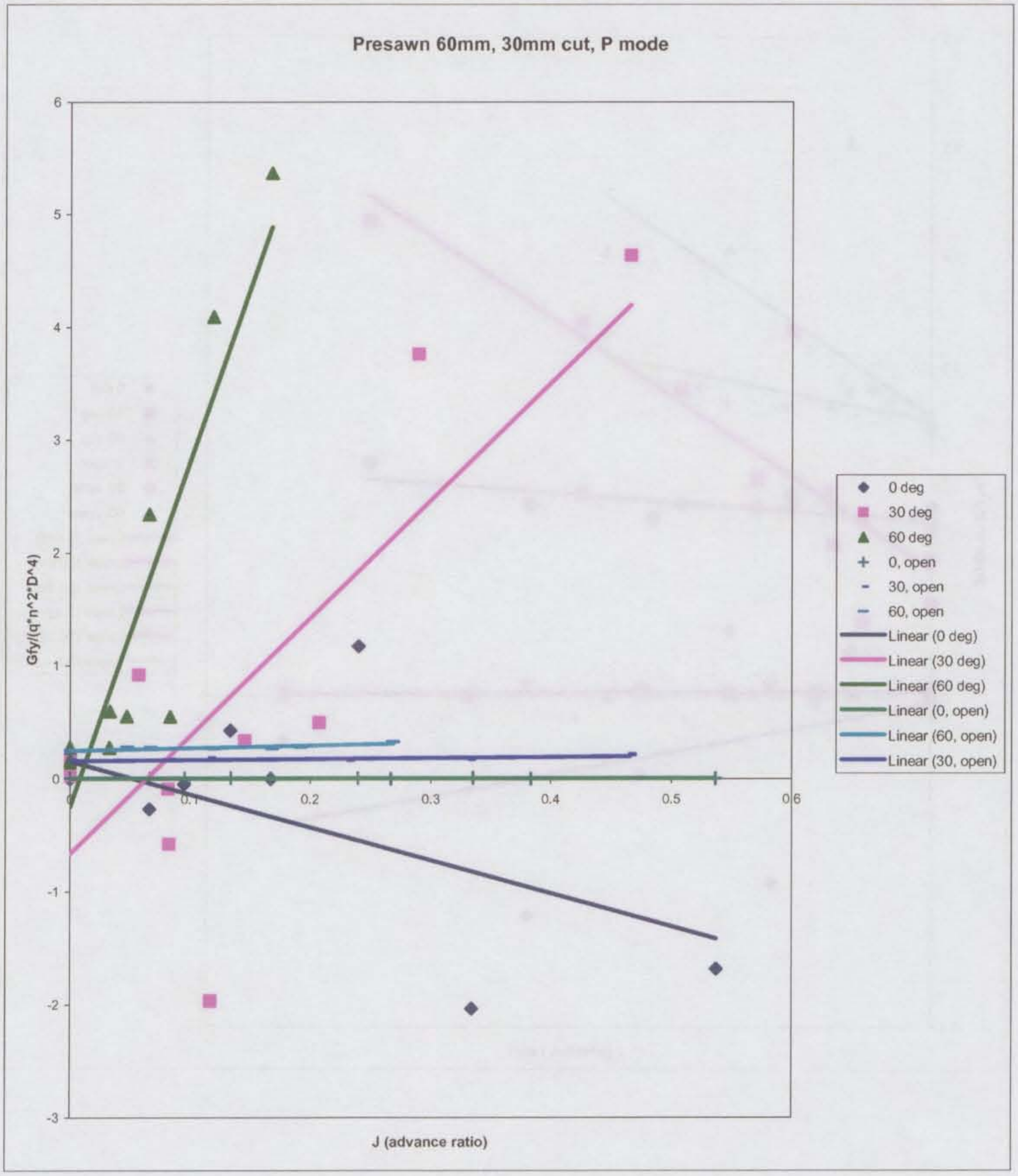

Pack Ice
10KQ
J (advance ratio)
0 Ice
30 Ice
0, Open
30, Open
Linear (0 Ice)
Linear (30 Ice)
Linear (0, Open)
Linear (30, Open)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

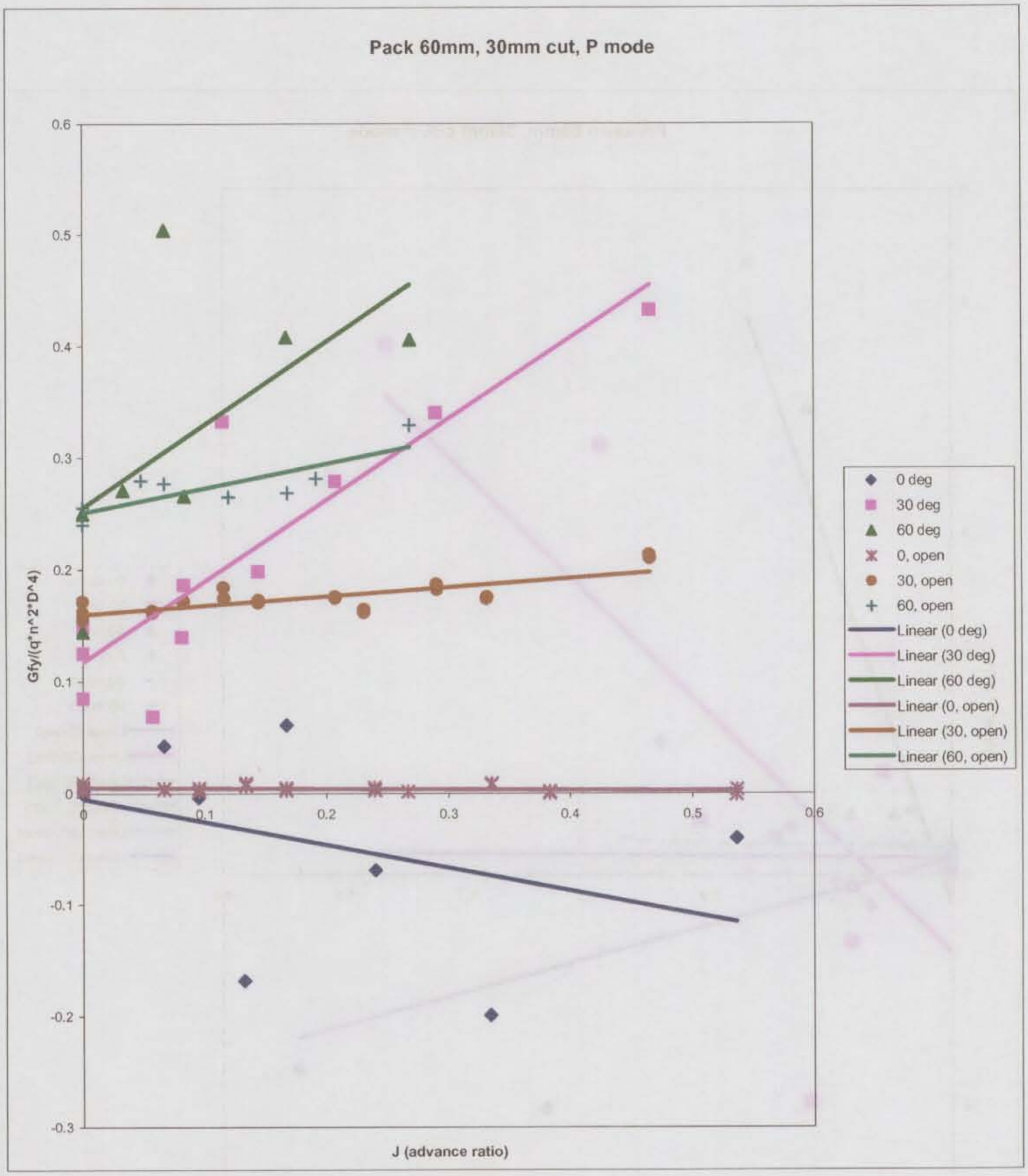
APPENDIX B

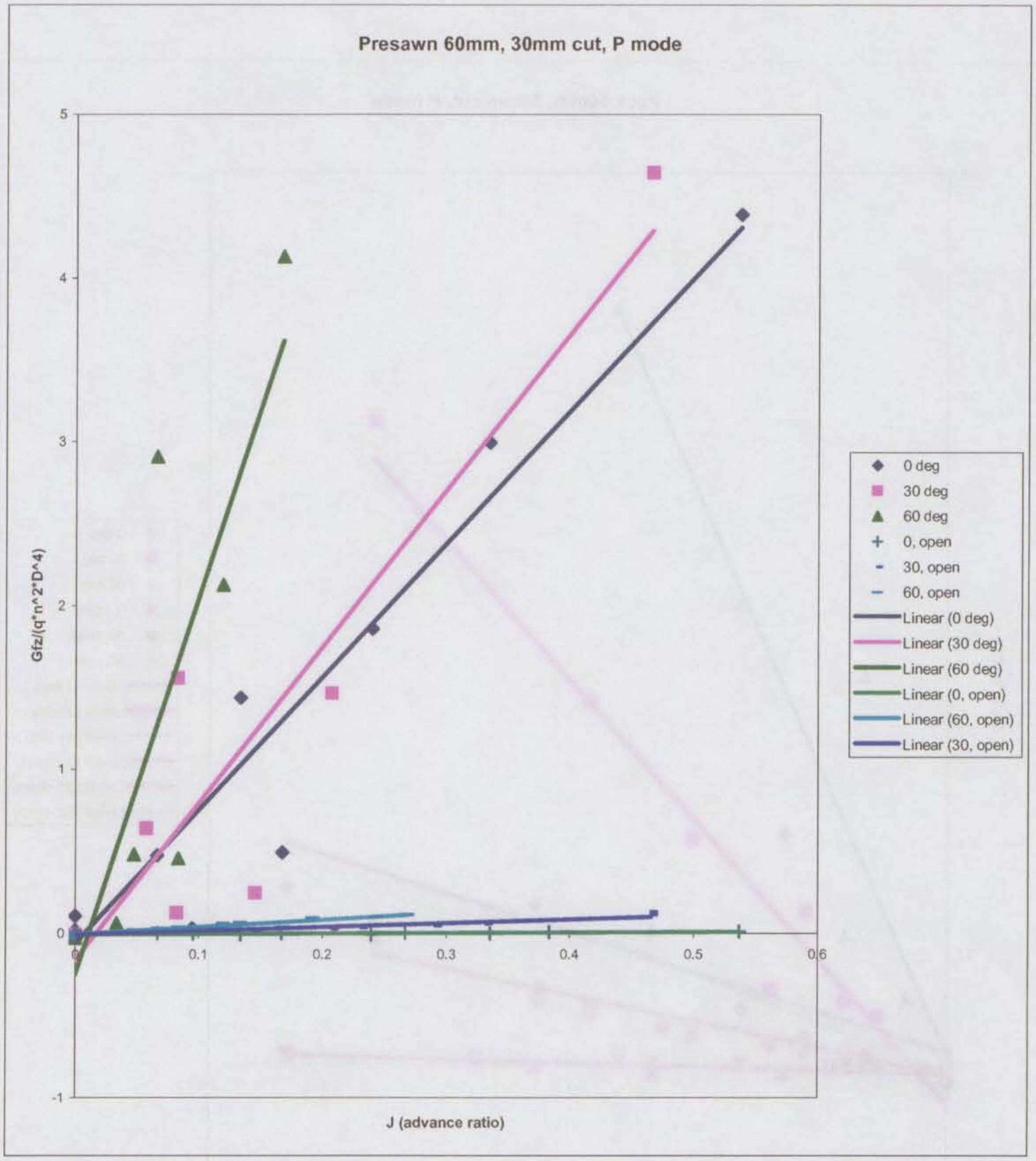
Results of Pusher Mode
(60 mm ice, 30 mm depth of cut)

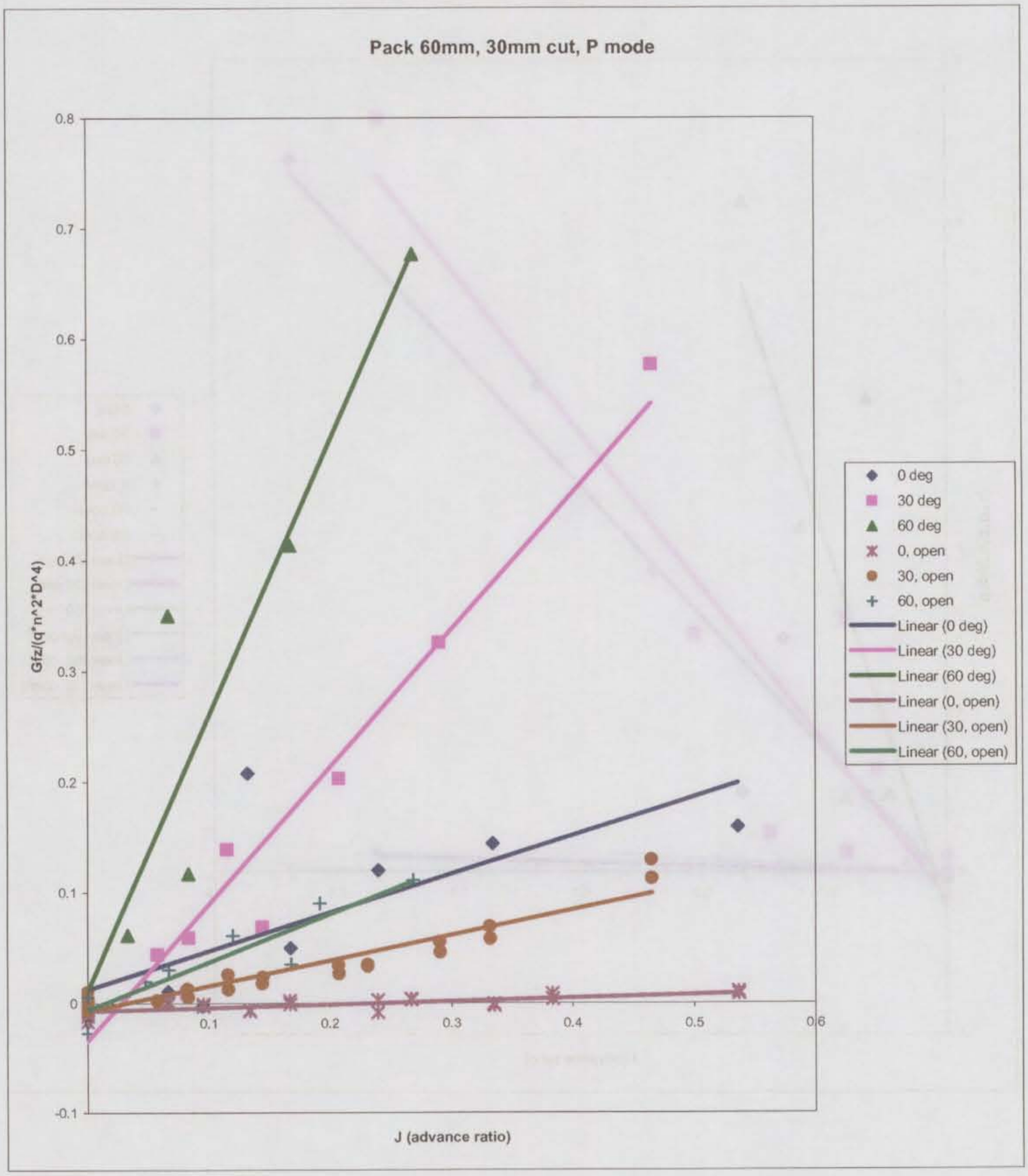



Pack 60mm, 35mm cut, P mode
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
0.1
0.2
0.3
0.4
0.5
0.6
Gfx/(q*n^2*D^4)
J (advance ratio)
0 deg
30 deg
60 deg
90 deg
0, open
30, open
60, open
90, open
Linear (0 deg)
Linear (30 deg)
Linear (60 deg)
Linear (90 deg)
Linear (0, open)
Linear (30, open)
Linear (60, open)
Linear (90, open)

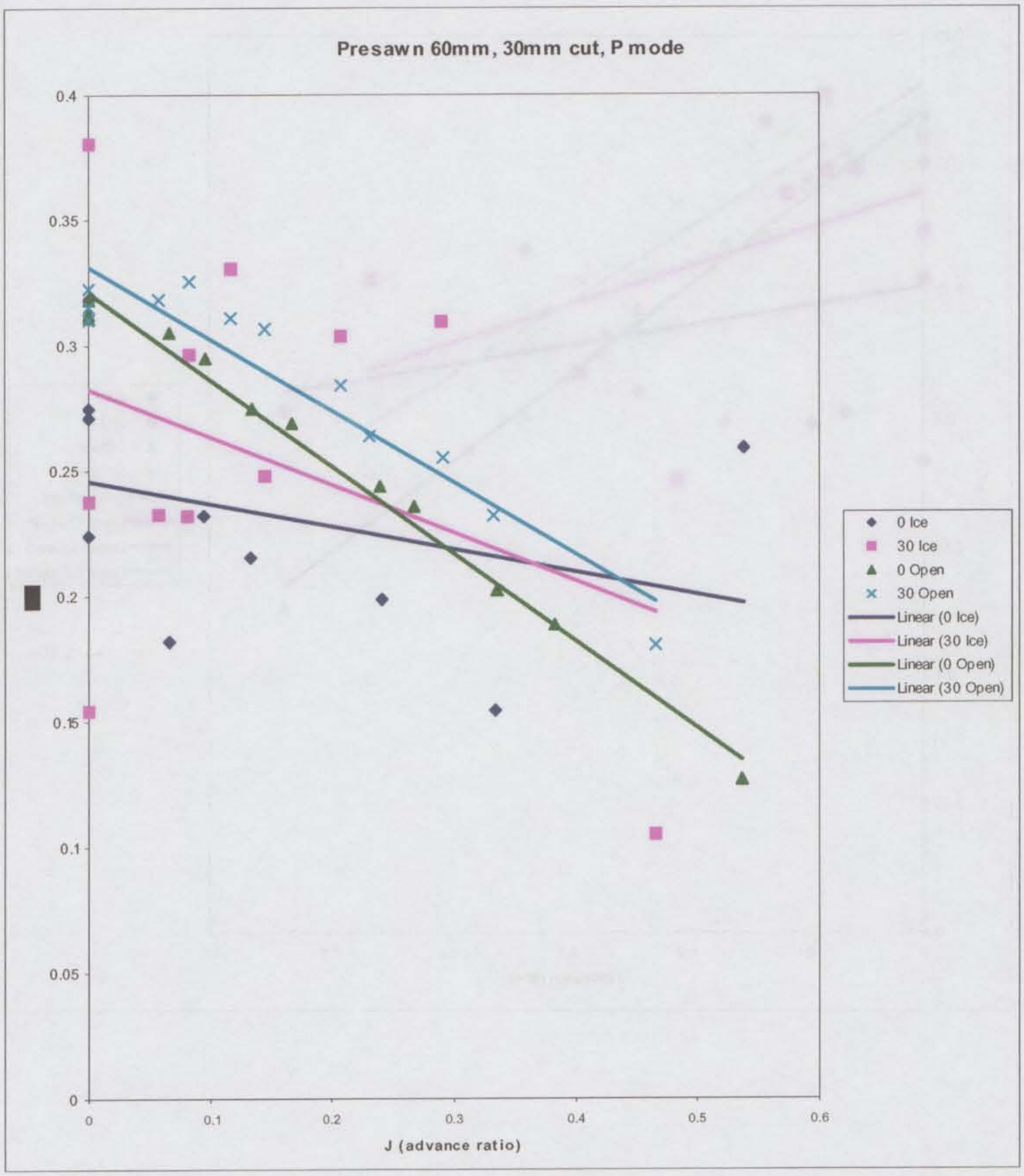

Presawn 60mm, 30mm cut, P mode
Gfy/(q*n^2*D^4)
J (advance ratio)
6
5
4
3
2
1
0
-1
-2
-3
0
0.1
0.2
0.3
0.4
0.5
0.6
0 deg
30 deg
60 deg
0, open
30, open
60, open
Linear (0 deg)
Linear (30 deg)
Linear (60 deg)
Linear (0, open)
Linear (60, open)
Linear (30, open)

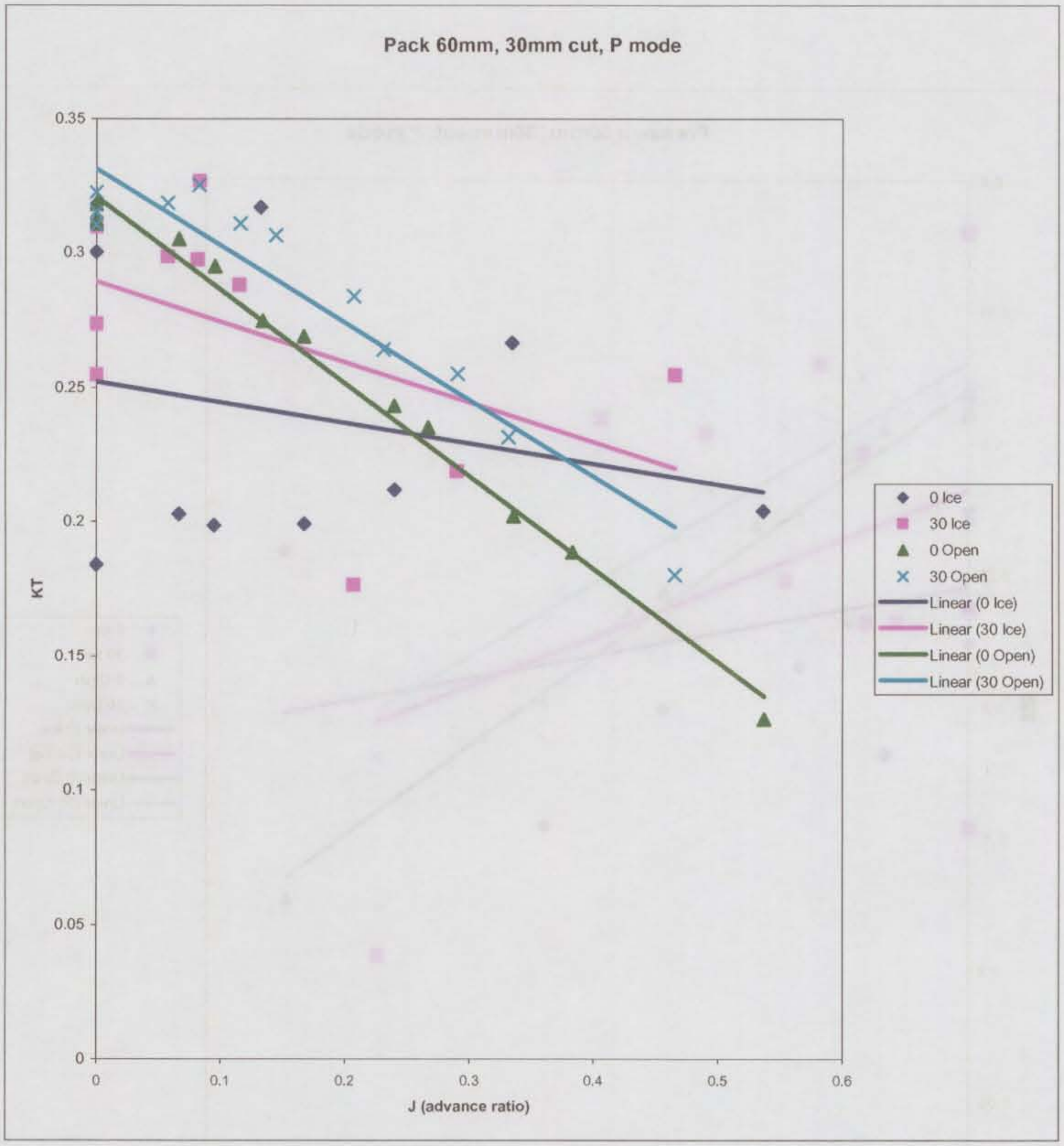

Pack 60mm, 30mm cut, P mode
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Gfy/(q*n^2*D^4)
0
0.1
0.2
0.3
0.4
0.5
0.6
J (advance ratio)
0 deg
30 deg
60 deg
0, open
30, open
60, open
Linear (0 deg)
Linear (30 deg)
Linear (60 deg)
Linear (0, open)
Linear (30, open)
Linear (60, open)

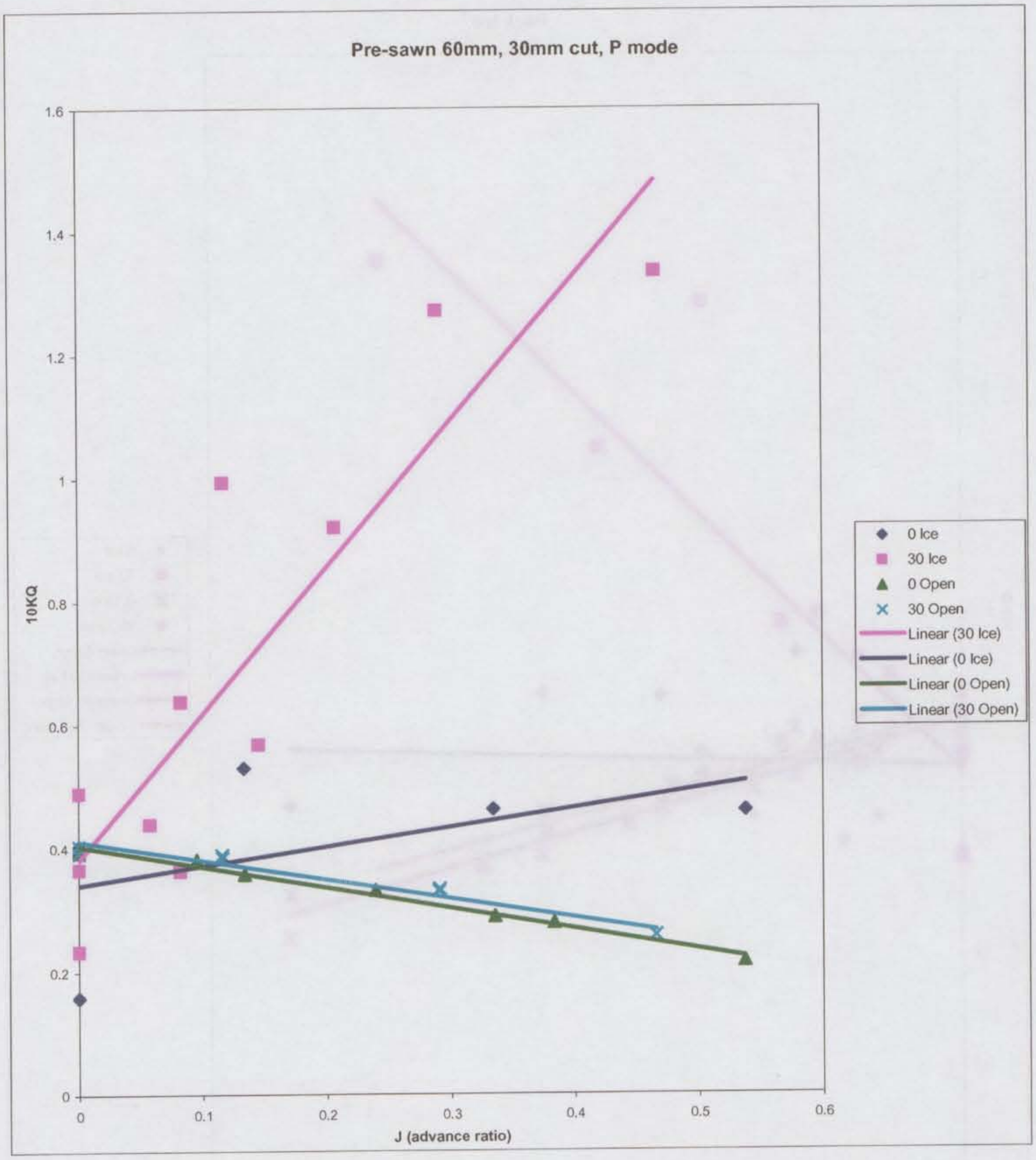

Presawn 60mm, 30mm cut, P mode
Gfz/(q*n^2*D^4)
J (advance ratio)
5
4
3
2
1
0
-1
0
0.1
0.2
0.3
0.4
0.5
0.6
0 deg
30 deg
60 deg
0, open
30, open
60, open
Linear (0 deg)
Linear (30 deg)
Linear (60 deg)
Linear (0, open)
Linear (60, open)
Linear (30, open)

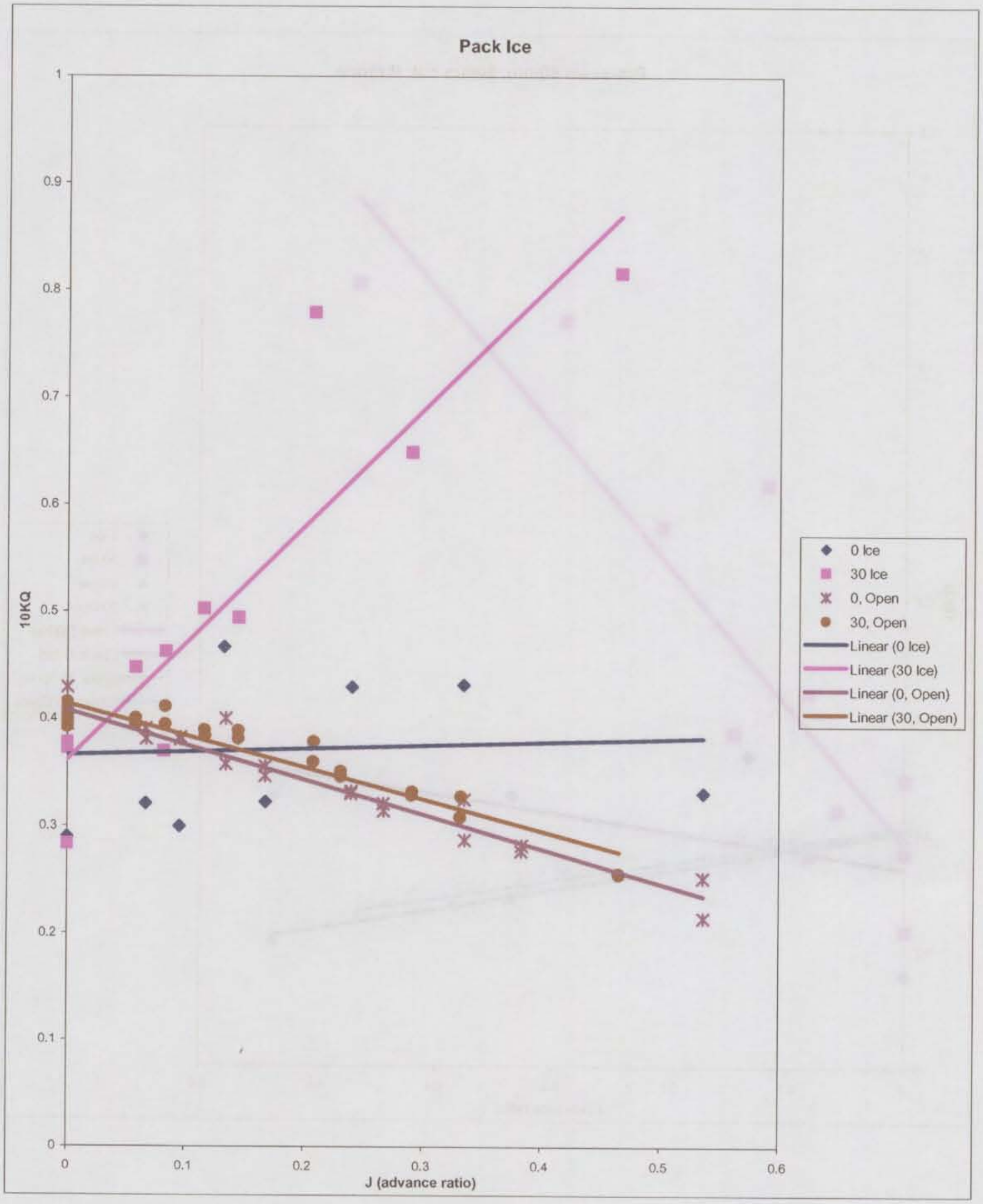


Pack 60mm, 30mm cut, P mode
Gfz/(q*n^2*D^4)
J (advance ratio)
0 deg
30 deg
60 deg
0, open
30, open
60, open
Linear (0 deg)
Linear (30 deg)
Linear (60 deg)
Linear (0, open)
Linear (30, open)
Linear (60, open)


Presawn 60mm, 30mm cut, P mode
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.1
0.2
0.3
0.4
0.5
0.6
J (advance ratio)
0 Ice
30 Ice
0 Open
30 Open
Linear (0 Ice)
Linear (30 Ice)
Linear (0 Open)
Linear (30 Open)


Pack 60mm, 30mm cut, P mode
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
KT
0
0.1
0.2
0.3
0.4
0.5
0.6
J (advance ratio)
0 Ice
30 Ice
0 Open
30 Open
Linear (0 Ice)
Linear (30 Ice)
Linear (0 Open)
Linear (30 Open)


Pre-sawn 60mm, 30mm cut, P mode
10KQ
J (advance ratio)
0 Ice
30 Ice
0 Open
30 Open
Linear (30 Ice)
Linear (0 Ice)
Linear (0 Open)
Linear (30 Open)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6


Pack Ice
10KQ
J (advance ratio)
0 Ice
30 Ice
0, Open
30, Open
Linear (0 Ice)
Linear (30 Ice)
Linear (0, Open)
Linear (30, Open)

APPENDIX C

Refer to enclosed CD
Final_Tared
Data_Analysis_opens
Report_Ice_Plots