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MECHANICAL PROPERTIES OF MULTI-YEAR SEA ICE, PHASE II

Progress Report 2

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by

G.F.N. Cox, J.A. Richter, W.F. Weeks and M. Mellor

U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, NH 03755

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INTRODUCTION

This progress report presents the results of the constant strain-rate triaxial tests which were performed during the months of January and February, 1983.

TRIAXIAL TESTS

Conventional triaxial tests were performed on the closed-loop testing machine using sample preparation and testing techniques similar to those employed in Phase I. As a result of our experience in Phase I, the triaxial cell was modified to increase its load bearing capacity to 350 kN (80,000 lbs) and confining pressure capacity to 24 MPa (3500 lbf/in.^{2}). Heavier latex membranes were also placed around the sample to prevent penetration of hydraulic fluid into the sample. A 22 kN (100,000 lb) load cell was provided by Shell to measure axial forces in excess of 11 kN (50,000 lb). The upper cylinder was also modified such that tests could be performed at confining pressure/axial stress ratios of 0.25 and 0.50.

A total of 55 triaxial tests were performed on multi-year pressure ridge samples at different test temperatures, strain-rates, and confining pressures. The number of tests at each test condition is summarized in Table 1. In Phase I, triaxial tests were performed on multi-year floe samples at axial stress/confining pressure ratios of 0.46 and 0.64 at the same temperatures and strain-rates.

Triaxial Strength

A detailed tabulation of the results from the triaxial tests is given in Appendix A. The average confined compresive strength of the ice, σ_1, for each test condition is plotted against the confining pressure ($\sigma_2=\sigma_3$) at faialure in Figure 1. Average uniaxial compressive strength data from

Table 1: Number of triaxial tests at different temperatures, strain-rates and axial stress/confining pressure ratios (σ_r/σ_a).

$\dot{\varepsilon}$ / T	$\sigma_r/\sigma_a = 0.25$		$\sigma_r/\sigma_a = 0.05$		
	10^{-5}/s	10^{-3}/s	10^{-5}/s	10^{-3}/s	
-5°C (23°F)	10V		9V	9V	28V
-20°C (-4°F)		9V	9V	9V	27V
	10V	9V	18V	18V	55V

V = Vertical

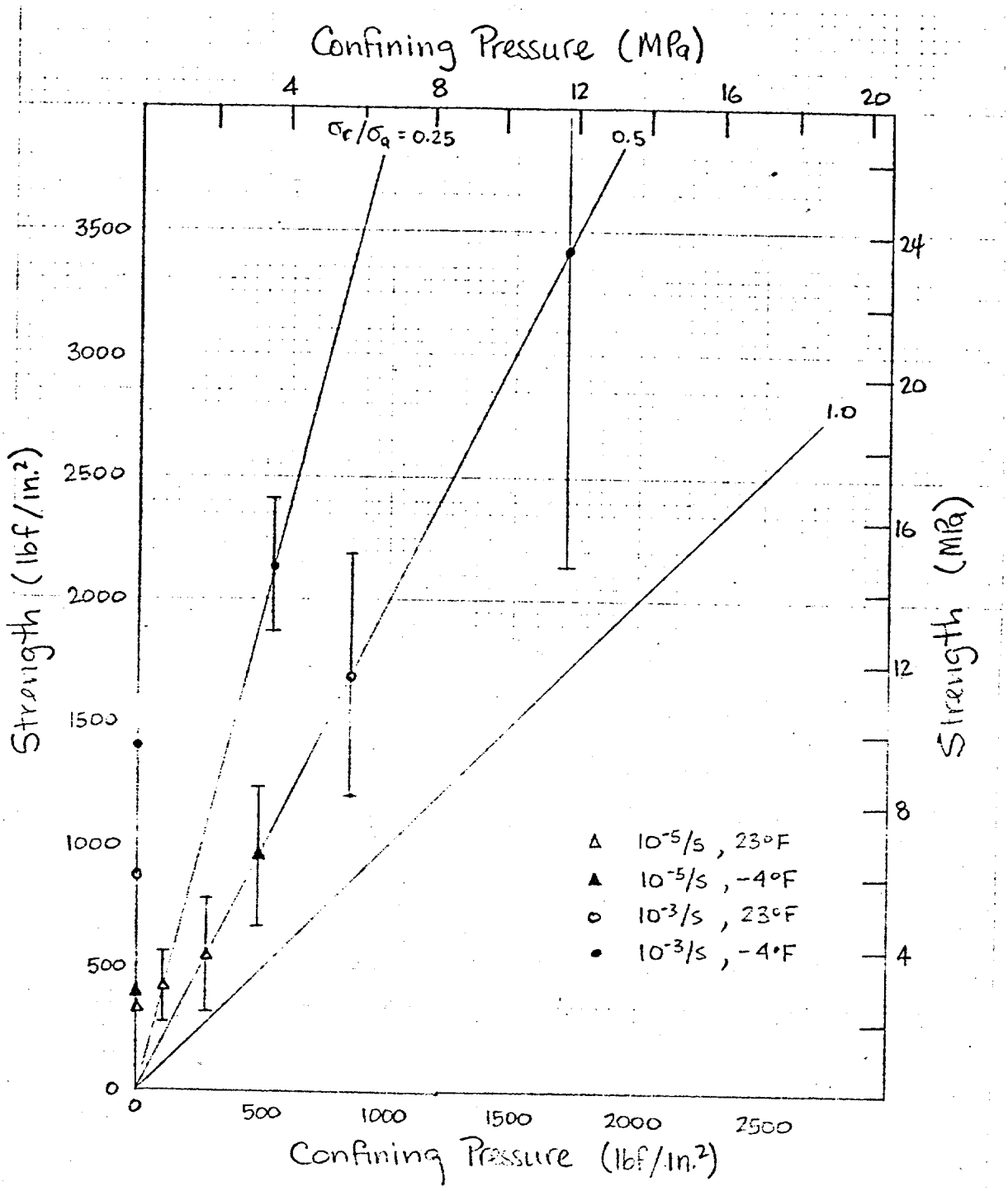

Figure 1: Compressive strength versus confining pressure for multi-year pressure ridge samples at different temperatures and strain-rates. The bars denote one standard deviation from the mean.

Phase I is included for comparison. In making comparisons between the unconfined and confined compressive strength data, it should be noted that the Phase I ridge samples had a much lower porosity. Table 2 summarizes the Phase II triaxial strength data.

As observed in Phase I, the confined compressive strength increases with decreasing temperature, increasing strain-rate, and increasing confining pressure. Due to variability of the ice structure between samples, the data show considerable scatter. The data at 10^{-5}/s suggests that failure of the ridge ice samples at low strain-rates may be described by a Tresca or Von Mises yield criteria. The yield surface paralles the hydrostat ($\sigma_r/\sigma_a = 1.0$). This supports the observations made by Jones who investigated the confined compressive strength of fresh water polycrystalline ice at low strain-rates.

The Phase II final report will also include a discussion on the initial tangent modulus data from the triaxial tests and examine the variation of the triaxial strength and modulus data with sample porosity.

Table 2. Summary of triaxial strength data.

	Triaxial Strength							
	Maximum		Minimum		Mean		Mean Porosity	
	(MPa)	(lbf/in.^{2})	(MPa)	(lbf/in.^{2})	(MPa)	(lbf/in.^{2})	(ppt)	Samples
-5°C (23°F)								
10^{-5}/s V, 0.25	3.95	573	1.14	166	2.86±0.98	415±142	79	10
10^{-5}/s V, 0.50	6.61	959	2.28	330	3.81±1.59	552±231	86	9
10^{-3}/s V, 0.50	17.94	2602	5.43	788	11.70±3.41	1697±495	78	9
-20°C (-4°F)								
10^{-3}/s V, 0.25	17.07	2475	11.58	1679	14.77±1.90	2141±275	77	9
10^{-5}/s V, 0.50	11.03	1600	3.95	573	6.59±1.97	956±286	82	9
10^{-3}/s V, 0.50	38.63	5602	8.34	1210	23.50±8.73	3408±1266	57	9

APPENDIX A

Triaxial Test Data

This appendix contains the results from the constant strain-rate triaxial tests (TRI). The parameters listed for each test are defined in the Index. As no displacement transducers were placed directly on the sample, the initial tangent modulus data given in Column 8 is based on the full sample strain. TRI-3-5/.5 denotes those tests conducted at a strain-rate of 10^{-3}/s, a temperature of -5°C, and a confining pressure/axial stress ratio of 0.5.

INDEX

Column No.	Symbol	Description
1	σ_m, psi	Peak Stress
2	ε_m(GL),%	Strain at σ_m determined by the DCDT's over a guage length of 5.5 inches
3	ε_m(FS),%	Strain at σ_m determined by the extensometer over the full sample length of 10 inches
4	t_m, sec	Time to peak stress
5	σ_e, psi	Stress at end of test
6	ε_e(FS),%	Full sample strain at end of test
7	t_e, sec	Time to end of test
8	E_i(GL),x10^6psi	Initial tangent modulus determined using strains found over the gauge length
9	E_o(GL),x10^6psi	Secant modulus determined using gauge length strains
10	E_o(FS),x10^6psi	Secant modulus determined using full sample strains
11	S_i,°/oo	Sample salinity at test temperature
12	ρ, lb/ft^3	Sample density at test temperature
13	V_b,°/oo	Brine volume at test temperature
14	V_a,°/oo	Air volume at test temperature
15	n,°/oo	Porosity at test temperature
16	σ_e /σ_m	Ratio of end to peak stress
17	Ice squareness, in	Sample squareness after ends are milled
18	End cap squareness, in	Sample squareness after endcaps are mounted
19	Shim, in	Amount of shim stock inserted between low end of sample and actuator before testing
20	ν_o	Initial Poisson's Ratio; circumferential and gauge length strain measurements used
21	ν_m	Poisson's ratio at peak stress; ε_m(C) and ε_m(GL) used
22	ε_m(C),%	Strain at σ_m determined by the circumferential extensometer

Also Note: FILE B-3-5 indicates Below Level Ice

10^{-3}/sec Strain Rate

-5°C Test Temperature

FILE TRI-5-5/.25

SAMPLE # 01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22
RA208-134/161 460	0.940	930.0	360	5.00	5000				0.049	0.03	51.12	0.3	107.6	107.9	0.783	0.009	0.000	0.000			
RA208-166/193 427	0.790	750.0	310	5.00	5000	0.707			0.054	0.04	52.77	0.4	78.9	79.3	0.726	0.004	0.003	0.004			
RA208-198/225 366	0.920	940.0	326	5.00	5000	0.168			0.040	0.16	51.22	1.4	106.1	107.5	0.891	0.009	0.007	0.008			
RA208-259/280 515	0.580	590.0	334	5.00	5000	0.408			0.089	0.80	52.65	7.3	82.1	89.4	0.649	0.003	0.006	0.006			
RB212-077/104 166	0.360	342.0	165	5.00	5000	0.217			0.046	1.24	54.60	11.7	48.9	60.6	0.994	0.004	0.004	0.004			
RB212-163/190 555	1.000	999.0	377	5.00	5000	0.309			0.056	0.12	53.34	1.1	69.1	70.2	0.679	0.008	0.002	0.002			
RB212-194/221 549	1.000	999.0	376	5.00	5000	0.245			0.055	0.33	53.75	3.1	62.3	65.3	0.685	0.009	0.009	0.010			
RB213-066/093 286	0.450	444.0	230	5.00	5000	0.179			0.064	1.03	54.05	9.6	58.1	67.7	0.804	0.009	0.016	0.016			
RB213-097/124 253	0.390	390.0	201	5.00	5000	0.194			0.065	1.21	53.73	11.2	64.0	75.2	0.794	0.010	0.006	0.006			
RA208-290/317 573	0.790	820.0	402	5.00	5000	0.291			0.073	0.79	54.10	7.4	56.9	64.3	0.702	0.011	0.007	0.008			

FILE TRI-5-5/.5

SAMPLE # 01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22
RA210-236/263 330	5.000	5000					0.172			0.09	47.23	0.7	175.6	176.3		0.010	0.008	0.008			
RA210-459/486 446	2.810	2810	442	5.00	5000	0.267			0.016	0.29	51.48	2.6	101.7	104.3	0.991	0.004	0.010	0.010			
RA210-536/563 895	0.960	960.0	641	5.00	5000	0.297			0.093	0.51	55.76	4.9	27.4	32.3	0.716	0.010	0.010	0.010			
RB213-255/282 362	0.650	660.0	350	5.00	5000	0.212			0.056	2.22	55.12	21.1	41.2	62.3	0.967	0.004	0.004	0.004			
RB216-230/257 489	0.730	730.0	430	5.00	5000	0.209			0.067	1.43	53.11	13.1	75.1	88.2	0.879	0.005	0.004	0.004			
RB216-330/357 350	0.910	910.0	330	5.00	5000	0.362			0.038	1.15	54.69	10.8	47.2	58.0	0.943	0.006	0.006	0.006			
RB217-367/394 577	0.900	910.0	525	5.00	5000	0.287			0.064	1.31	56.42	11.0	16.9	27.9	0.910	0.011	0.009	0.010			
RB217-443/470 959	0.520	540.0	625	5.00	5000	0.436			0.184	1.04	56.62	10.1	15.0	25.2	0.652	0.034	0.014	0.014			
RA210-372/399 557	1.320	1340	485	5.00	5000	0.339			0.042	0.09	45.66	0.7	203.1	203.8	0.871	0.006	0.006	0.006			

FILE TRI-3-5/.5

SAMPLE # 01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22
RA210-490/517 1830	0.590	5.80	1369	5.00	50.00	0.574			0.310	0.32	53.58	3.0	65.2	68.2	0.748	0.004	0.006	0.006			
RA211-233/260 1544	0.440	4.20	979	5.00	50.00	0.461			0.351	0.04	52.34	0.4	86.4	86.7	0.534	0.007	0.016	0.016			
RB213-286/313 1870	0.410	4.00	1432	5.00	50.00	0.650			0.456	1.34	55.14	12.7	39.5	52.2	0.766	0.010	0.003	0.004			
RB216-124/151 1926	0.520	4.70	979	5.00	50.00	0.685			0.370	1.50	53.32	13.8	71.5	85.3	0.508	0.007	0.010	0.010			
RB216-262/289 1294	0.350	3.10	1019	5.00	50.00	0.526			0.370	0.95	51.61	8.5	100.4	108.9	0.554	0.012	0.013	0.014			
RB217-236/263 1838	0.420	3.90	1424	5.00	50.00	0.601			0.438	0.40	53.13	3.7	73.2	76.8	0.775	0.005	0.006	0.006			
RB217-267/294 1584	0.600	5.60	1424	5.00	50.00	0.531			0.264	0.95	55.13	9.0	39.0	48.1	0.899	0.019	0.008	0.008			
RB217-399/426 2602	1.010	10.60	1806	5.00	50.00	0.715			0.258	0.62	56.51	6.0	14.5	20.6	0.694	0.016	0.005	0.006			
RA210-059/086 788	0.280	2.80	788	5.00	50.00	0.419			0.281	0.02	48.38	0.2	155.5	155.7	1.000	0.025	0.004	0.004			

FILE TRI-3-20/.25

SAMPLE # 01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22
RA208-025/052 2125		0.610	6.00	1114	5.00	50.00	0.482		0.348	0.02	50.07	0.1	128.0	128.0	0.524	0.004	0.002	0.002			
RA208-340/367 2467		0.700	7.20	995	5.00	50.00	0.334		0.352	1.10	56.46	3.6	17.7	21.4	0.403	0.031	0.012	0.012			
RA211-078/105 1679		0.460	4.60	1679	0.46	4.60	0.428		0.365	0.02	50.95	0.1	112.6	112.7		0.006	0.002	0.002			
RA211-127/154 1822		0.470	4.80	740	5.00	50.00	0.470		0.388	0.03	49.36	0.1	140.3	140.4	0.406	0.010	0.004	0.004			
RB212-132/159 2475		0.650	6.40	1066	5.00	50.00	0.555		0.381	0.23	52.60	0.7	84.1	84.8	0.431	0.007	0.003	0.004			
RB212-326/353 2157		0.610	6.30	1027	5.00	50.00	0.297		0.354	1.28	54.89	4.1	45.2	49.3	0.476	0.006	0.004	0.004			
RB212-047/074 1974		0.610	6.10	788	5.00	50.00	0.546		0.324	0.81	53.36	2.5	71.4	73.9	0.399	0.003	0.006	0.006			
RB212-239/266 2236		0.580	5.70	931	5.00	50.00	0.589		$386.0	1.70	55.39	5.5	36.9	42.4	0.416	0.007	0.004	0.004			
RB213-156/183 2332		0.690	6.90	1027	5.00	50.00	0.536		0.338	1.58	55.48	5.1	35.3	40.4	0.440	0.007	0.005	0.006			

FILE TRI-5-20/.5

SAMPLE # 01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22
RA210-90/117 740	5.000	5000					0.303			0.03	50.33	0.1	123.4	123.5		0.004	0.007	0.008			
RA210-133/160 851	1.520	1530	851	5.00	5000	0.479		0.056		0.03	50.94	0.1	112.8	112.9	1.000	0.000	0.005	0.006			
RA211-266/293 1039	0.700	710.0	772	5.00	5000	0.297		0.148		0.04	51.92	0.1	95.8	95.9	0.743	0.007	0.006	0.006			
RB216-156/183 573	5.000	5000					0.282			1.96	50.55	5.8	121.3	127.1		0.005	0.010	0.010			
RB216-188/215 820	1.010	1030	820	5.00	5000	0.300		0.081		0.66	51.88	2.0	97.0	99.0	1.000	0.006	0.022	0.022			
RB216-361/388 971	0.780	750.0	812	5.00	5000	0.318		0.124		1.00	55.71	3.3	30.7	33.9	0.836	0.025	0.004	0.004			
RB216-432/459 1600	0.680	670.0	947	5.00	5000	0.452		0.235		1.47	56.53	4.9	16.9	21.7	0.592	0.015	0.010	0.010			
RB217-191/218 963	1.390	1380	939	5.00	5000	0.386		0.069		0.53	53.11	1.6	75.5	77.1	0.975	0.007	0.013	0.014			
RB217-335/362 1050	1.100	1110	955	5.00	5000	0.391		0.095		1.83	54.96	5.9	44.5	50.4	0.910	0.008	0.005	0.006			

FILE TRI-3-20/.5

SAMPLE # 01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22
RA210-194/221 2674	0.610	5.40	1942	5.00	50.00	0.830			0.438	0.02	51.77	0.1	98.4	98.4	0.700	0.002	0.004	0.004			
RA210-341/368 2578	0.790	7.80	1958	5.00	50.00	0.689			0.326	0.11	51.48	0.3	103.5	103.8	0.760	0.011	0.003	0.004			
RA210-567/594 4011	0.880	8.50	2196	5.00	50.00	1.021			0.456	0.83	56.43	2.7	18.0	20.7	0.547	0.007	0.003	0.004			
RB213-225/252 3008	0.680	6.60	1448	5.00	50.00	0.901			0.442	2.22	55.25	7.2	39.9	47.0	0.481	0.004	0.004	0.010			
RB213-342/369 4584	1.000	9.40	2992	5.00	50.00	0.936			0.458	1.65	55.60	5.4	33.2	38.6	0.653	0.004	0.004	0.004			
RB216-089/116 3374	0.490	4.50	3374	0.49	4.50	0.838			0.689	0.29	52.55	0.9	85.0	89.9		0.006	0.004	0.004			
RB216-392/419 3629	0.910	9.00	1974	5.00	50.00	0.860			0.399	1.78	56.22	5.8	22.6	28.4	0.544	0.007	0.010	0.010			
RB217-052/079 1210	0.210	2.00	1210	0.21	2.00	0.639			0.576	0.14	53.71	0.4	64.7	65.1		0.007	0.002	0.002			
RB218-363/390 5602	1.200	12.00	2929	5.00	50.00	1.000			0.467	0.55	56.60	1.8	14.8	16.6	0.523	0.005	0.005	0.006			

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