North Dakota Soybean Council Semi-Annual Report

a. Research Project Title, Principal and Co-Investigators

Project Title: "Design of High-Performance Materials by Using Soybean Meal as a Functional "Feedstock

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b. Research Overview and Objectives

Project Overview:

In a previous study funded by ND Soybean Council, we have demonstrated that Soybean Meal (SBM) has cementitious properties which is activated by heat and pressure, and it has the capacity to absorb water like high performance water absorbent like vermiculite. In this proposal, we will fundamentally design high strength cementitious structures with durable properties by tailoring the protein content and surface properties by coating with bioplastics. Once the high strength cement with tailored durability has been designed then we will manufacture high strength concrete and/or aggregates by using SBM. The SBM-based concrete and composites will be a game changer as it will create high performance building materials from renewable biomass whose valuation is low. We will also explore the absorbent potential of SBM as a potential reservoir for absorbing emerging contaminants like Per- and Polyfluoroalkyl Substances (PFAS) from water supplies for farm usage which is in direct alignment with the RFP to create "Ag for Ag new uses application". The successful completion of these two critical thrust areas will create a demand for high volume SBM usage which will create large quantities of SBM usage use in cement and absorbent sector. The project is in direct alignment with research priority areas 1,2,4 and 9 of ND Soybean Council.

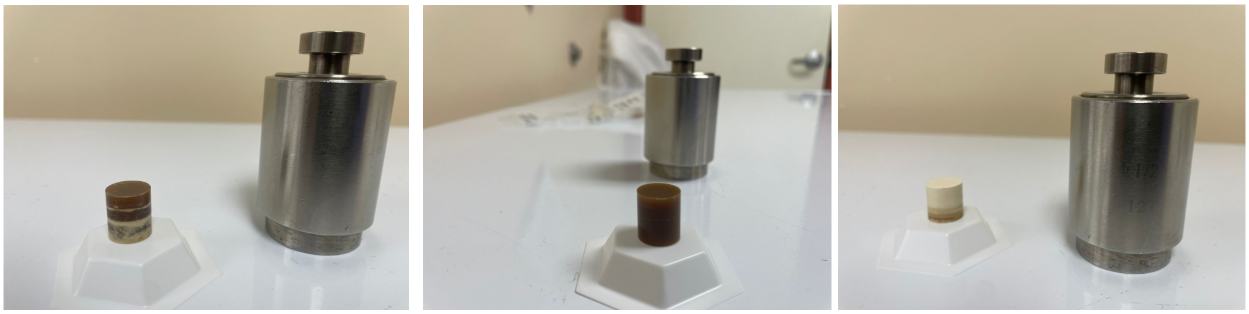
Objectives: The project will have four objectives:

1. Optimize the physical and mechanical behavior of SBM-based composites by tailoring the protein and carbohydrate content in the matrix.
2. Increase the durability of the cementitious composites by developing coatings of hydrophobic polymers like Polylactic Acid (PLA) on SBM particles.
3. Design high performance concrete by using optimized SBM as the cementing phase.
4. Design biosorbents from SBM for absorbing Per- and Polyfluoroalkyl Substances (PFAS).

c. Progress of Work and Results to Date

c.1 Progress in Objective-1: This study was conducted by the graduate student under the supervision of Drs. Gupta and Ji

Two different pure soybean meal samples T and S were collected from different sources and dried at 100^oC for 24hrs. The samples were milled with the use of a shatter box for 7 minutes and sieved with 100 mesh. Samples T and S of masses 2.6 and 2.3 g (initial weight, W_1) respectively were measured and fabricated using a ½ inch die. The samples were then cold pressed for 30 seconds twice at 3 U.S tons and afterwards, subjected to hot pressing at 250^oC at 1 gauge pressure for 23 minutes and a hold temperature of 5 minutes. The pressure was then increased to 8 gauge for the next 5 minutes before the experiment was terminated. The die was allowed to cool down and the samples were retrieved. The final weight, W_2 (**Figure 1**) and dimensions was measured and recorded as shown in **Tables 1 and 2**. The samples were then subjected to compression test and the stress – displacement plots were generated as shown in **Figures 3-6**. The lubricant used for this study was WD40. The experiment was carried out with or without die lubrication.



a b c

Figure 1: a (sample T with lubrication), b (Sample T without lubrication) and c (sample S)

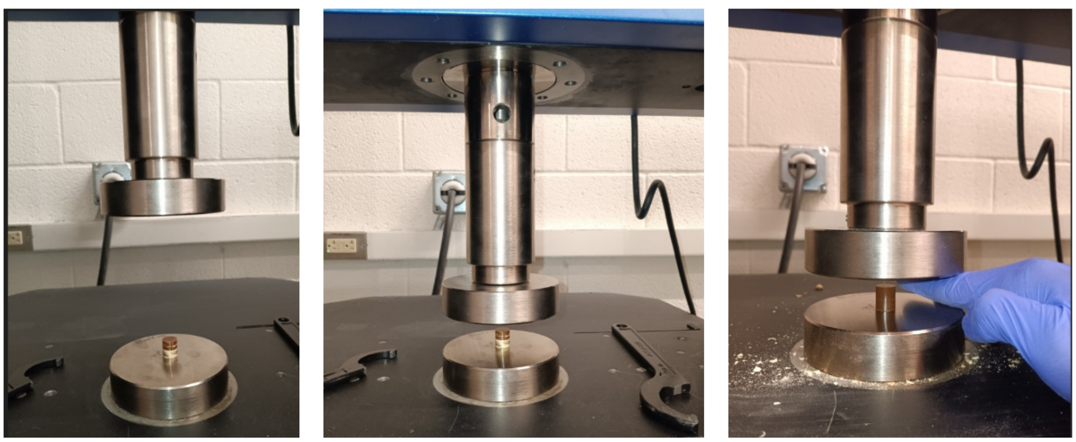
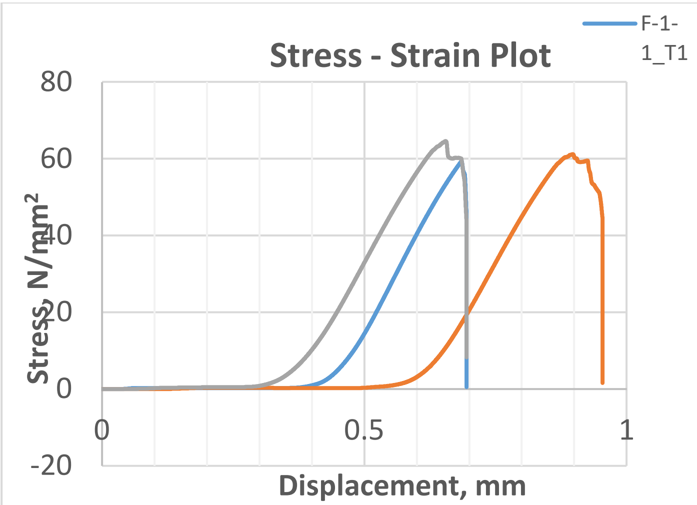


Figure 2: Compression test

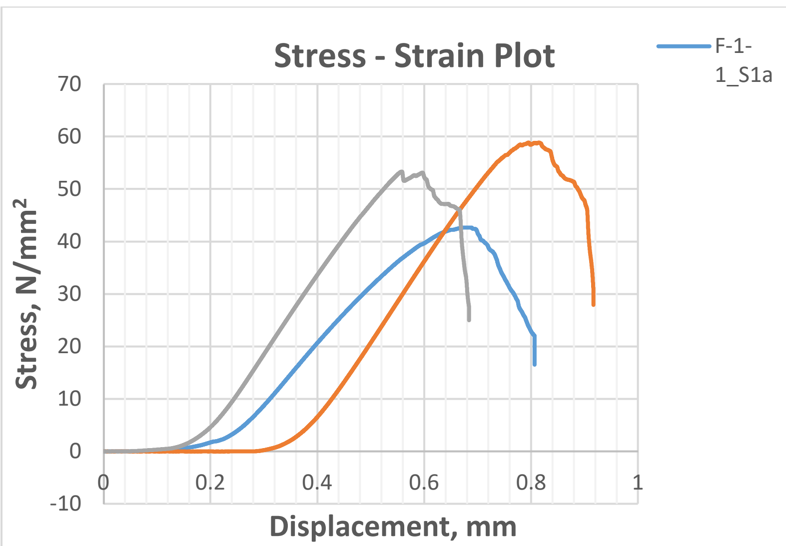
Table 1: With lubrication: Samples T and S

S/N	Samples	H (mm)	D (mm)	W_1 (g)	W_2 (g)
1	F-1-1-S1a	13.77	12.73	2.33	2.327
2	F-1-3-S1b	13.19	12.74	2.3	2.2682
3	F-1-4-S1c	13.48	12.71	2.3045	2.2885
4	F-1-1-Ta	14.27	12.72	2.6	2.54
5	F-1-2-Tb	14.41	12.71	2.6	2.5487
6	F-1-3-Tc	14.37	12.66	2.6	2.5346



sample	Maximum Stress N/mm^2
F-1-1_T1	59.35
F-1-2_T2	61.26
F-1-3_T3	64.63
Mean	61.75
STDEV.S	2.67
RSD	4.30%

Figure 3: Stress – Strain curve for Soy bean meal T (with lubrication)

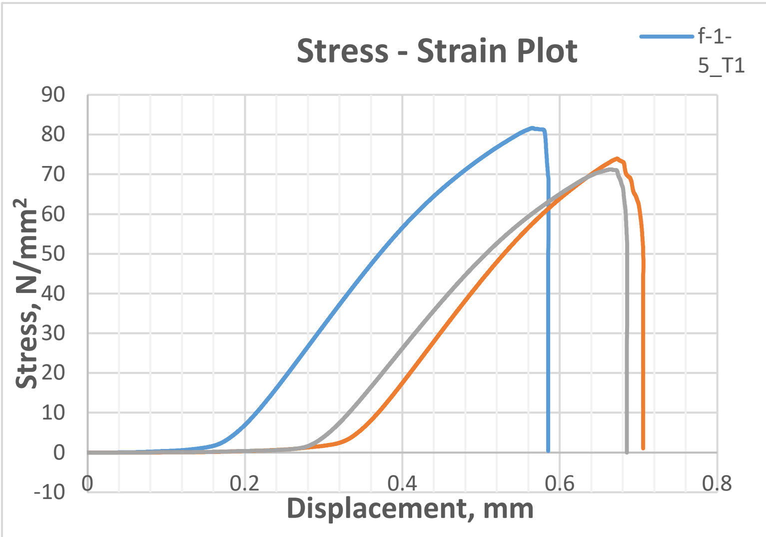


Samples	Maximum Stress N/mm^2
F-1-1_s1a	42.71
F-1-3_s1b	58.90
F-1-4_s1c	53.38
Mean	51.66
STDEV.S	8.23
RSD	15.92%

Figure 4: Stress – Strain curve for Soy bean meal, Sample S (with lubrication)

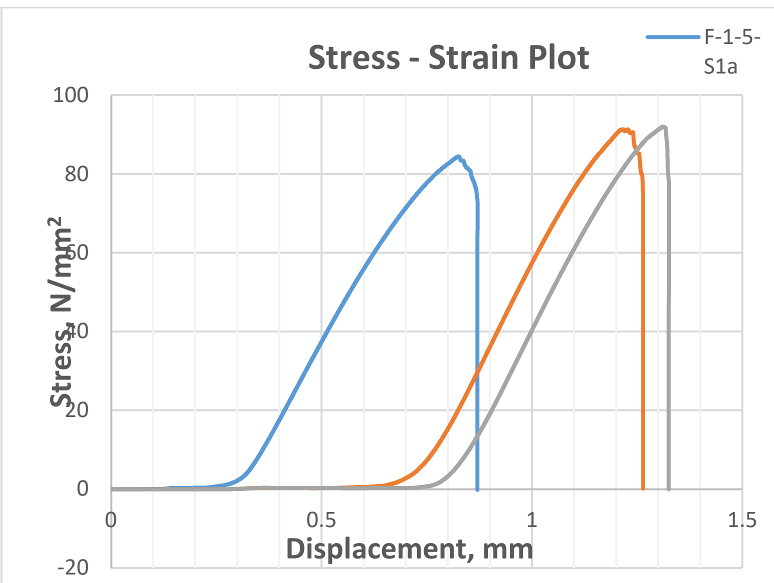
Table 2: Without lubrication: Samples T and S

S/N	Samples	H (mm)	D (mm)	W_1 (g)	W_2 (g)
1	F-1-5-S1a	13.09	12.71	2.3049	2.2444
2	F-1-5-S1b	13.19	12.74	2.3072	2.2689
3	F-1-6-S1c	13.48	12.71	2.3045	2.2885
4	F-1-5-T1	14.62	12.69	2.603	2.5777
5	F-1-5-T2	14.41	12.69	2.6061	2.572
6	F-1-6-T3	14.50	12.67	2.6029	2.567



Samples	Maximum Stress N/mm^2
F-1-5_T1	81.70
F-1-5_T2	73.98
F-1-5_T3	71.30
Mean	75.66
STDEV.S	5.40
RSD	7.14%

Figure 5: Stress – Strain curve for Soy bean meal, Sample T (without lubrication)



Sample	Maximum Stress N/mm^2
F-1-5_s1a	84.46
F-1-5_s1b	91.37
F-1-5_s1c	92.03
Mean	89.29
DTDEV.S	4.19
RSD	4.69%

Figure 6: Stress – Strain curve for Soy bean meal, Sample S (without lubrication)

Summary

Composites were fabricated using a ½ inch die. The mean maximum stress obtained from the compressive tests conducted were for lubricated die were 61.75 N/mm^2 (deviation of 2.67) for sample T and 51.66 N/mm^2 (deviation of 8.23) for sample S while samples for non-lubricated die were 75.66 N/mm^2 (deviation of 5.40) for sample T and 89.29 N/mm^2 (deviation of 4.19) for sample S. The effect of die lubrication may be responsible to the low strength of samples T and S. This may be as a result of the reaction between the lubricant and the soybean meal during hot pressing. This effect was cancelled from the strength of materials fabricated without lubrication, hence leading to increased strength of the sample T from 61.75 N/mm^2 to 75.66 N/mm^2. The same trend occurred with the strenth of sample S which increased from 51.66 N/mm^2 to 89.29 N/mm^2. <u>By optimizing the fabrication parameters, we have increased the strength of the</u>

Soybean-based cement to 89±4.2 MPa. We are currently working on understanding the effect of protein and carbohydrate phase on the strength development, and waiting for proximate data from NDSU.

c.2 Progress in Objective-2: Student is conducting literature survery

c.3: Progress in Objective-4:

We have successfully prepared highly porous biofoam samples by using Soybean Meal (SBM). The samples were processed at 300 and 900 ^oC, respectively. We have designed membranes from these samples and have tested contaminated water with PFAS for purification. We are currently waiting for the analysis data.

Table 3: Summary of properties of Soybean Meal and Hemp

Composition	Temperature (°C)	Comments	Density (g/cc)	True Density (g/cc)	Porosity (%)	Compressive Strength (MPa)
50% SBM-50% Hemp	300°C	NA	0.88±0.03	1.43	38.7%	13.45±1.09
50% SBM-50% Hemp	900°C	Small cracks on the sides, slightly bulged	0.84±0.01	1.96	57.40%	18.61±5.83

d. Completed Work: Deliverables and/or Milestones.

Milestones-1: Have fabricated high strength samples by using different types of Soybean Meal (SM). Currently, we are waiting for proximate analysis data for achieving further understanding about the strengthening mechanisms in the composites.

Milestone-2: Have designed SBM-based membrane for filtering PFAS-laden water.

e. Work to be Completed.

We are following the workplan given in the proposal.

f. Other relevant information: potential barriers to achieving objectives, risk mitigation strategies, or breakthroughs.

One of the critical issue which we are facing is the high amount of water absorption by SBM-based composites. We plan to mitigate it by developing durable coatings of hydrophobic corn-based polymers like PLA on SBM. We will also functionalize the water absorption behavior of SBM by designing it as a functional constituent in cement. In addition, we will document the potential of these composites as potential materials for bioremediation of contaminants like PFAS.

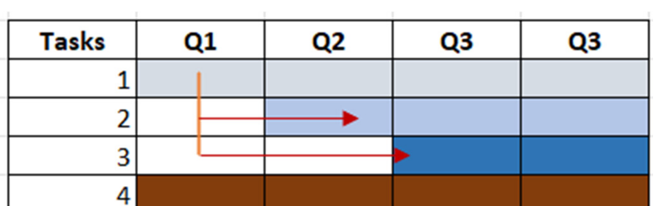


Figure 7: GANTT chart for deliverables

g. Summary

The work is progressing according to the proposed plan. Figure 7 shows GANTT chart of the project.