# Design and Commercialization of High Value Functional Products from Soybean Meal

An Interim Report (07/1/2023)
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# 1. Introduction

## 1.1 Background on Soybean Meal (SM)

World's 85% of Soybean crop is processed into Soybean Meal (SM) and oil [1, 2]. The oil component is used for human consumption, bio-diesel component etc. Comparatively, SM component is predominantly used for animal feed. In 2020, US used 34 million metric tons and exported 11.88 million metric tons [3]. Currently, SB has a low valuation of 0.42 USD/Kg [4]. Solvent extraction is the common method for extraction of oil from soybean with 1.5% oil being left in SM during the process [5].

## 1.2 Alternative Usage of SM – A Literature Survey

SM has some inherent advantages like low cost, biodegradability, and processability [6] which makes it a unique materials system for advanced materials research which is underutilized. Protein-rich SB has some disadvantages like poor mechanical behavior and poor water resistance due to presence of hydrophilic groups which has hindered design of materials from this precursor [6-8]. Recently, some studies have focused on designing and manufacturing SM-based adhesives, but the process used during manufacturing is tedious and involves intermediate steps like chelation [6], cross-linking [7], and hybridization [8]. These intermediate steps further increase the difficulty in commercialization of these materials. In addition, the authors have not found any background study where the material system has beneficially used 1.5% residual oil in the SM-matrix for further applications. Furthermore, the beneficial and synergistic usage of environmentally friendly SM for designing high performance functional materials with high profit margin is underutilized.

## 1.3 Preliminary Data

Dr. Gupta's team is in the process of developing collaboration with Mr. Mike Keller from ADM which was facilitated by Dr. Scott Korom. During this process, ADM supplied SM to Dr. Gupta's team at UND. We were successfully able to process it into particles of different size-fractions (Fig. 1b) (Fig. 1a shows example of bioplastics feedstock powder). In addition, we used hot pressing to design and manufacture bioplastics (Poly-lactic Acid (PLA))-SM composites (Fig. 1c) where PLA is a bioplastic processed from Corn (we have designed technology to design different types of bioplastics which will further give us competitive edge for commercialization). These composites have unique surface appearance which can be further leveraged for different

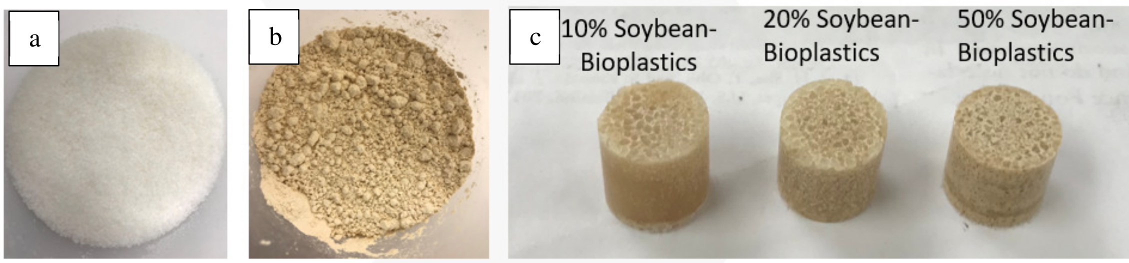



**Figure 1: Digital pictures of, (a) bioplastic powder (poly-lactic acid (PLA)), (b) milled and sieved SM, and (c) composites of SM with bioplastics (picture courtesy: Dr. Zhang).**

types of applications like packaging and infrastructure. Figure 2 shows the technology to design solvent-cast thin films by using SM-bioplastics with different visual appearance. It is also possible to machine these films and consolidate them into pressed-samples (Fig. 2e). As a background, bioplastics are renewable and biodegradable polymers, for example PLA is derived from renewable sources [9]. Previously, Soybean oil has been integrated with PLA to design biodegradable materials [9]. Thus, the integration of SM with bioplastics will create *unique renewable material systems for large-scale valorization and commercialization*.

Design of novel SM-based renewable products will be a win-win situation for all the stakeholders from commercialization perspective as traditional polymers are not sustainable and as high as 40% of the produced plastics is thrown away [10].

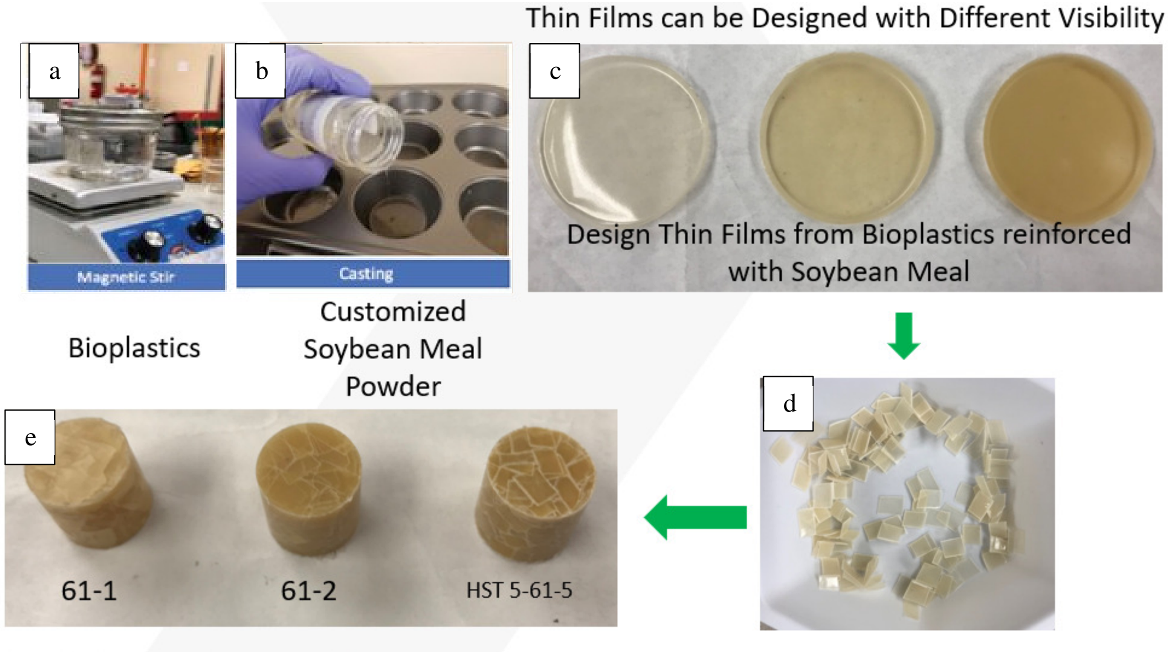



**Figure 2: Digital pictures of, (a) stirring process), (b) liquid ink (images courtesy: Saud et al. JMEP), and (c) solvent-cast films, (d) machined coupons, and (e) hot-pressed samples (pictures courtesy: Dr. Zhang).**

## 2. Integrated Research Program

This proposal will address the "New Use Research Priorities" of, (a) Soybean Meal (SM) Use and (b) Potential Commercialization. As integral component of this research, we are proposing a hypothesis driven design paradigm which beneficially use SM for manufacturing high performance materials with high valuation in high growth market areas. It is also proposed that the design will effectively use residual oil in SM-matrix for lubrication applications which will open potential avenue of synergistic usage of SM and Soybean oil for rapid commercialization.

During the research, we had proposed following objectives:

Objective 1: To create *novel pathways* of creating SM-based feedstock;

Objective 2: To create *transformative methods* for manufacturing novel sustainable composites by using SM;

Objective 3: To *understand* the mechanical, tribology, and durability of the composites by experimental studies.

Objective 4: To *formulate strategy for commercializing* the materials developed during work in phase-II.

## 3.1 Progress on Different Objectives:

### 3.1.1 Development of Scaffold Technology

In this project, a graduate student (Temofeh) and Dr. Zhang are working with the PIs. Figure 1 shows the manufacturing paradigm for manufacturing scaffolds. During this study, we designed scaffolds by integrating different fractions of Poly Lactic Acid (PLA) with Soybean Meal (SM).

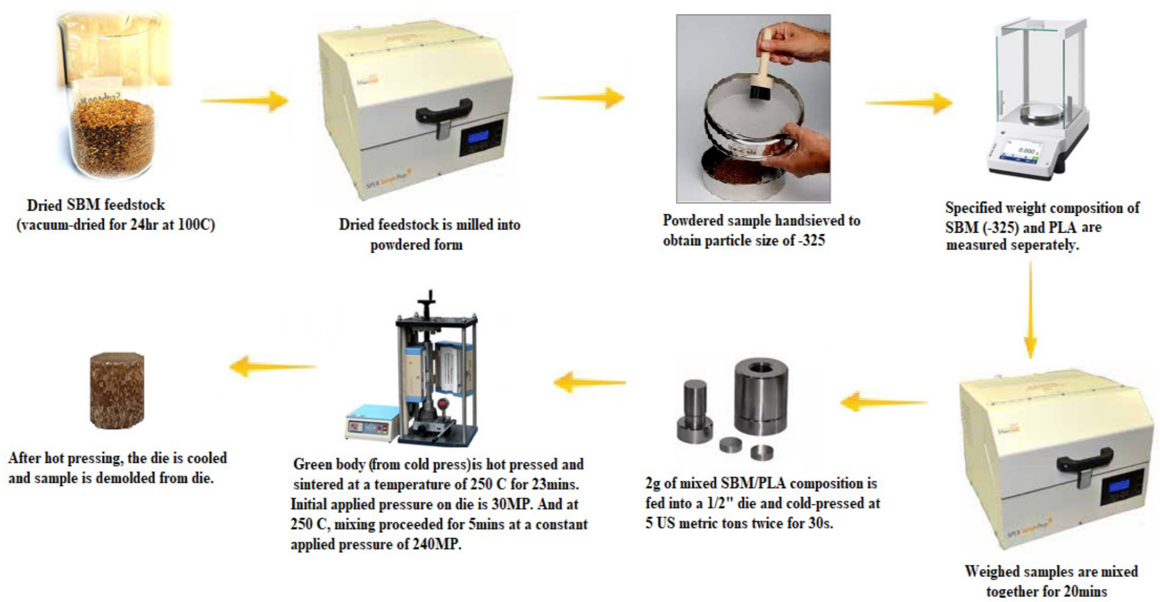



Figure 3: Processing paradigm for manufacturing Soybean Meal based Scaffolds (picture courtesy: Mr. Temofeh).

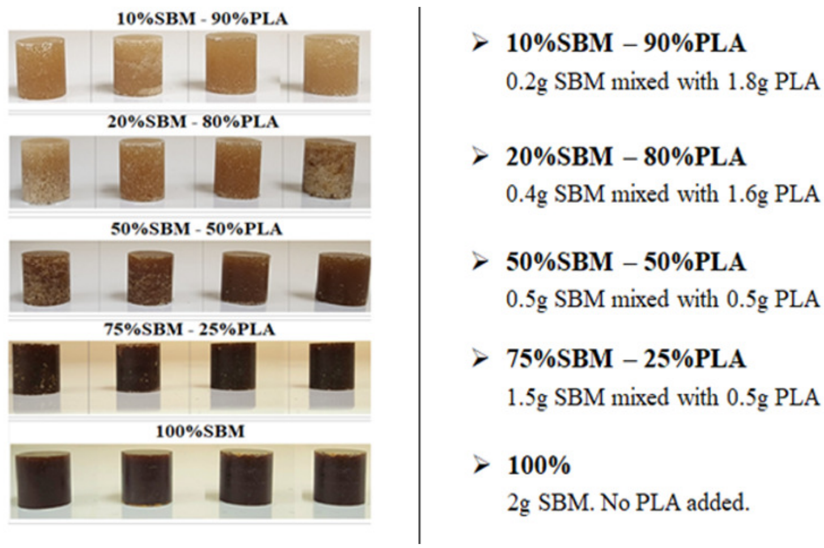



Figure 4: Different samples synthesized during this study

Figure 4 shows the digital pictures of these composites. Figure 5 shows the compressive strength behavior of these composites. By using SM, it is possible to design composites with dry strength of >80 MPa. We are classifying SM-based composites as SM-cement. However, the addition of PLA lower the strength of the composites due to weak interactions of PLA with SM matrix. Figure 6 shows the thermal characterization of the composites. They have melting points greater than 150 $^{o}$C which make them useful for many applications.

Figure 7 shows the SEM images of PLA-SB composites. Although SM based composites showed high strength, the detailed investigation of microstructure revealed presence of micro-cracking the SM matrix. Figure 8 summarizes the water absorption results of hot-pressed Soybean Meal composites. These composites can absorb greater than 100 wt% water which may be useful in water absorption applications like plant growth. Figure 9 shows the variation of friction coefficient versus distance of hot-pressed Soybean Meal. The composition has a low dry friction coefficient which makes them useful for many solid lubricant applications.

Table 1: Summary of bulk density of different PLA-SM composites

| Composition (wt%) | Avg. Diameter (mm) | Avg. height (mm) | Avg. Volume (cm³) | Avg. Mass (g) | Avg. bulk density (g/cm³) |
|---|---|---|---|---|---|
| 10%SBM - 90%PLA | 12.72 ± 0.01 | 12.48 ± 0.04 | 1.58 ± 0.01 | 1.99 ± 0.00 | 1.26 ± 0.00 |
| 20%SBM - 80%PLA | 12.73 ± 0.01 | 12.41 ± 0.04 | 1.58 ± 0.01 | 1.99 ± 0.01 | 1.26 ± 0.01 |
| 50%SBM - 50%PLA | 12.71 ± 0.01 | 11.86 ± 0.04 | 1.50 ± 0.01 | 1.98 ± 0.00 | 1.32 ± 0.00 |
| 75%SBM - 25%PLA | 12.71 ± 0.00 | 11.53 ± 0.09 | 1.46 ± 0.01 | 1.99 ± 0.00 | 1.37 ± 0.01 |
| 100%SBM | 12.71 ± 0.01 | 11.11 ± 0.13 | 1.41 ± 0.02 | 1.99 ± 0.02 | 1.41 ± 0.00 |

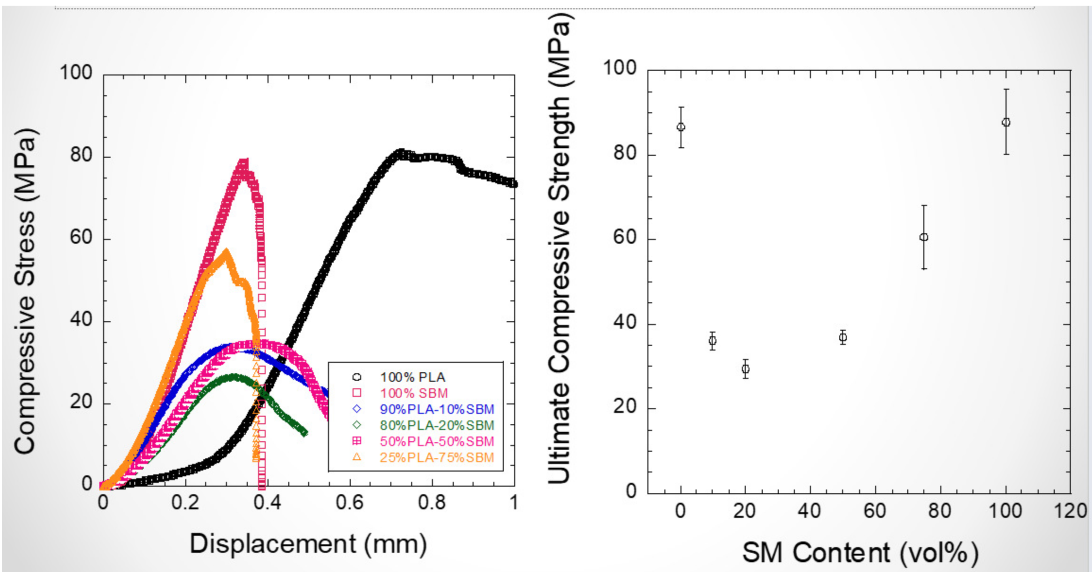



Figure 5: Plot of, (a) compressive stress versus displacement, and (b) ultimate compressive strength versus Soybean Meal Content.

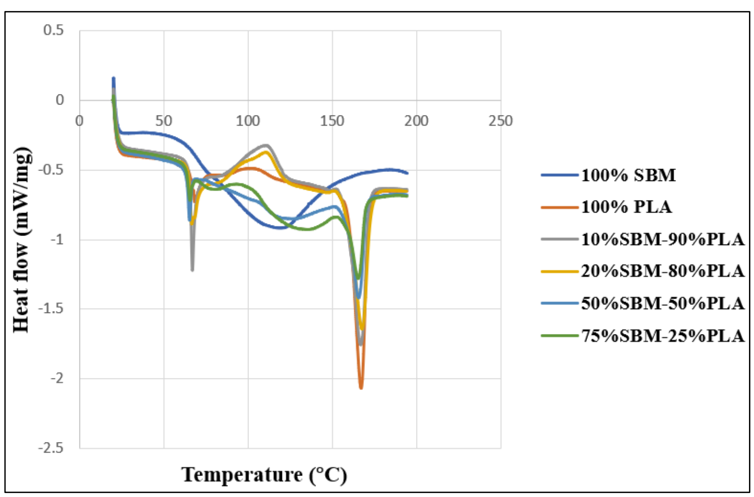



Figure 6: Thermal characterization of the composites

### 2.1.2 Development of Solvent Cast Technology

Figure 2 shows the manufacturing process of solvent casting technology. The team was successfully able to fabricate PLA-SM composite films. Figure 10 shows the tensile strength behavior of solvent cast films. All the composites showed plastic behavior. Figure 11 summarizes the ultimate tensile strength behavior of SM-PLA composites. This work shows that we can add 40% SBM as additives in PLA matrix. Currently, we are characterizing these films for further evaluation as bioplastics for different applications like packaging etc.

## 3. Summary of Current Progress

We have completed Objective-1 where we processed SM particles as feedstock for composite design. We are currently working on Objectives 2-4. We have identified SM-based composites as potential green cement with hydrophilic and water absorption properties which will allow us to compete with green cements. Figure 12 shows a case study where we have designed SM-sand composites for potential concrete based applications. These compositions shows high strength which further strengthens our case for designing SM-based high strength compositions. Currently, we are developing different enzymatic processes for isolating protein and carbohydrate components of SM-based composites. We are also developing a collaboration with Dr. Miranda for tailoring the chemistry of proteins for further enhancing the strength of these composites. These studies will further strengthen the patent application.

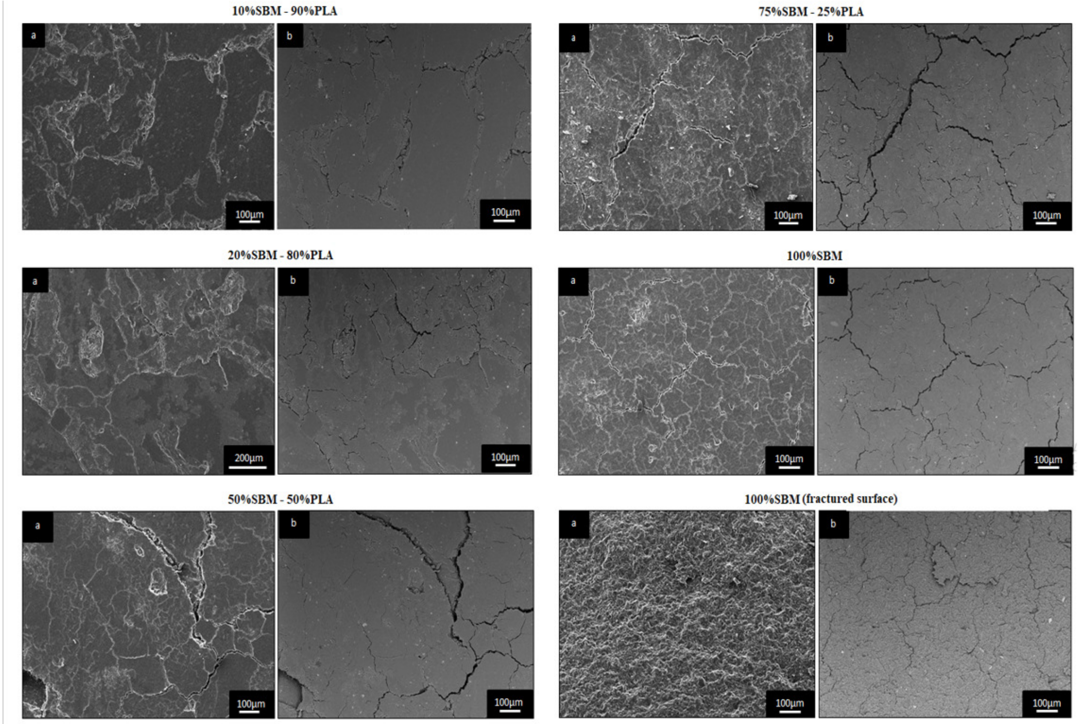



Figure 7: SEM micrographs of PLA-SBM composites.

| Water absorption test | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Composition | Dry Mass (g) | Hours | | | | | | | | |
| | | 0 | 1 | 2 | 4 | 8 | 24 | 72 | 120 | 144 |
| 100% SBM (8 guage) | 1.9737 | 0.00% | 20.20% | 30.29% | 42.18% | 62.99% | 106.17% | 91.26% | 87.21% | |
| | 1.9834 | 0.00% | 19.99% | 29.46% | 43.99% | 65.26% | 109.17% | 92.51% | 92.04% | |
| | 1.9958 | 0.00% | 19.76% | 28.89% | 42.50% | 62.64% | 108.09% | 93.75% | 88.09% | |
| Average | 1.9843 | 0.00% | 19.98% | 29.55% | 42.89% | 63.63% | 107.81% | 92.51% | 89.11% | |

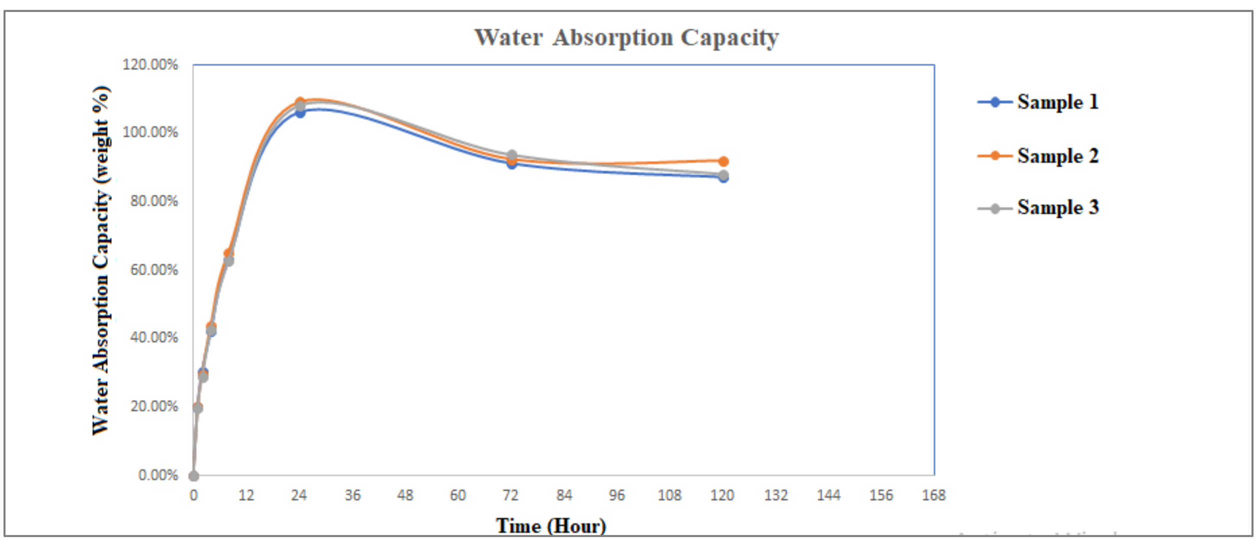



Figure 8: Water absorption results of different samples

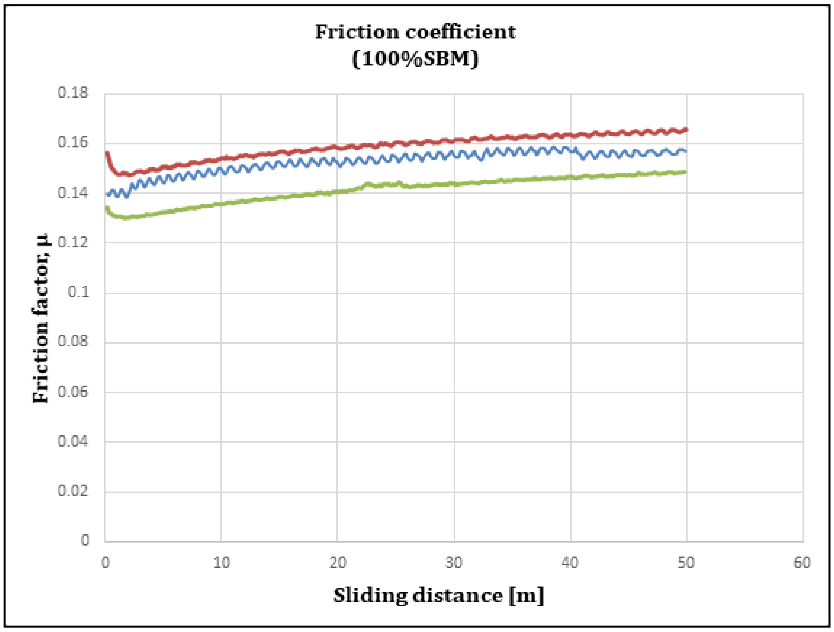



Figure 9: Friction coefficient versus sliding distance of hot pressed Soybean Meal.

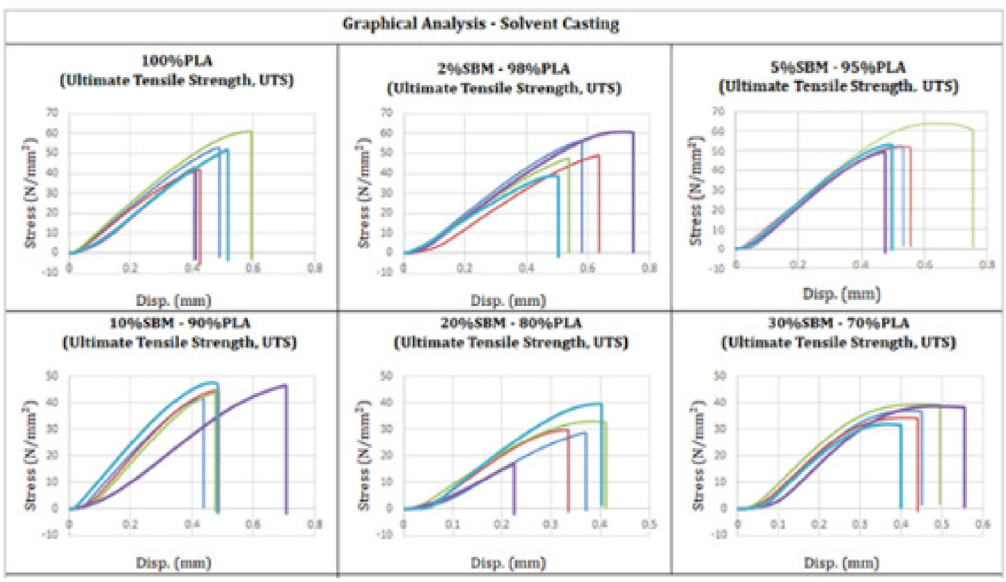
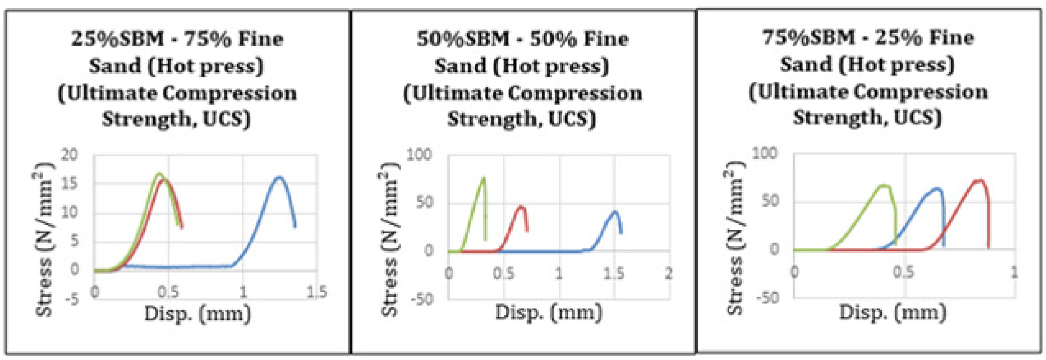



Figure 10: Summary of tensile stress versus displacement behavior of composites


Figure 11: Summary of tensile strength behavior of composites (all values are in MPa).




| Composition (wt%) | Avg. UCS (Mpa) Sample 1 | Sample 2 | Sample 3 | Avg. UCS (Mpa) |
|---|---|---|---|---|
| 25%SBM - 75%Sand (Hot press) | 16.16 | 15.79 | 16.87 | 16.27 ± 0.55 |
| 50%SBM - 50%Sand (Hot press) | 41.35 | 47.22 | 76.39 | 54.99 ± 18.77 |
| 75%SBM - 25%Sand (Hot press) | 63.92 | 72.87 | 68.03 | 68.27 ± 4.48 |

Figure 12: Summary of mechanical performance of SM-based composites with sand

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