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# Multi-material Composite-Based SLS Printer Interfaced with GUI

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***Abstract*— Selective Laser Sintering technology is a type of additive manufacturing with an increasing interest in many applications. This technology has a great potential to enhance the multi-material based manufacturing. Due to the increasing complexity of the multi-material based manufacturing, there is a need for a simplified operational interface. This paper proposes a Graphical User Interface (GUI) for multi-material based SLS printer to maintain complex parameters and perform simple calculations properly. The GUI is based on Rule of Mixture (ROM) which considers Monte Carlo Simulation (MCS) approach to increase the performance accuracy. The interface takes inputs from ten pre-defined polymers and performs the calculation according to the requirement. In the end, the GUI results were verified by the FEA simulation.**

***Index Terms*— Additive manufacturing, multi-material, SLS printer, polymer, filament**

## I. INTRODUCTION

Selective Laser Sintering (SLS) is a technology that utilizes a laser to harden and bond small-sized grains of plastic materials into layers in a 3D structure [1]. The laser hardens the material by tracing each cross-section pattern of the 3D design onto powder bed. The bed lowers when the first layer is built and begins to build the second layer on top of the first layer. The process of lowering the bed and building the layers continues until every layer is produced and the 3D part is completed. SLS 3D printers use a pulsed laser because the density of the finished part depends on the peak laser power rather than the duration of the laser [2]. It should be noted that the SLS printers preheat powder materials located in the powder bed below the melting point of the powder to ease the process of raising the temperature of specified regions to the melting point during the manufacturing process. SLS 3D printing has several advantages compared to some other additive manufacturing methods. In comparison with Stereolithography (SLA), and Fused Deposition Modelling (FDM) 3D printing technologies, SLS 3D printers do not require the support structures to prevent the printing part from collapsing or deforming during fabrication [3, 4].

Elimination of additional support structures provides the opportunity for manufacturers to reduce the number of material usage, manage the budget efficiently, and reduce production time. Also, powder bed can be packed with a large number of materials allowing higher productivity of manufacturing operations. Traditional manufacturing technologies require assembling processes after the parts are fabricated separately. However, SLS 3D printers can manufacture consolidated objects, thus; eliminating the need to assemble separate parts and saving time on assembly. Also, SLS 3D printers allow manufacturers to produce sophisticated and complex geometries that no other printing methods can produce [5]. Therefore, the SLS technology is able to manufacture complex shapes and geometries directly from CAD data which makes it be used widely around the world for many applications [6]. However, SLS printers cannot fabricate hollow enclosed parts because it will not be possible to drain the non-sintered powder from the fabricated objects. Nowadays, Selective Laser Sintering machines can use one or two powder materials to manufacture parts and full equipment. Powders are usually produced by ball milling process. The single component powder is common for Direct Metal Laser Sintering [7]. However, the majority of SLS printers utilize two-component powders. In comparison with other additive manufacturing methods, SLS can build parts from a wider range of powder materials that are commercially available in the market, including polymers, alloys, polystyrene, metals, and composites [8, 9]. Also, SLS allows manufacturers to control the physical process: the option of printing operation can be full melting, partial melting or liquid phase sintering. This crucial feature provided by SLS printing machines triggers it to become a popular method for building prototypes and final products. SLS has been increasingly used in industries that require a small number of high-quality parts. For instance, the aircraft industry sector often produces elements in small quantities so that it is not cost effective to manufacture physical molds for parts [10]. Therefore, aerospace industry notes the creation of prototypes for aircraft by using SLS additive manufacturing as an excellent solution. Based on the observation, it can be stated that SLS 3D printing is a crucial method of producing parts for different applications in the industry.

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## II. LITERATURE REVIEW

### A. The Development Direction of the SLS

The copyright of the patent number 5597589 called "Apparatus for producing a part by selective laser sintering" was expired on January 28, 2014, and it was a milestone of 3D printing revolution [11]. Previously, the SLS printers were only available in some industries with a high price, however, when the patent was expired, more and more researches became interested in this area of research. It is expected that cost-effective SLS printers will come up with the possible future modifications in several directions to improve the technology. Currently, SLS printing is being developed in several directions, for example, one of them is by defining the correlation between the energy consumption and material optimization to increase the energy efficiency of this technology [12]. Recently proposed technology demonstrates a numerical model that takes into account the interactions of the laser beam and powder bed, temperature parameters of the used materials, solid-liquid phase transition, and then, by investigating the prediction models developed to elaborate efficiency maps [13]. However, potentially the big step of improvement can be achieved by multi-material layer usage in this printing technology, which is currently limited by one material only in each layer. The enhancement in powder mixing and dispensing technologies allows to multi-material SLS printing [14]. This direction of the development of 3D printing can give significant results. Therefore, the development of Graphical User Interface (GUI) based on the Rule of Mixture has been proposed.

### B. Application of Multi-materials in 3D Printing

Currently, the usage of multi-materials is a technically and economically auspicious method of manufacturing. The application of single materials in a 3D printing process sometimes cannot meet the requirements of some products that need multi-material components, such as complex mechanisms, 3D circuits, medical implants, human tissues, and so on. Lightweight or low-cost products can be developed using multi-materials. Nowadays, the manufacturing industry already takes advantage of using multi-materials in several applications, which include a coating of internal surfaces, and constructing electronic circuits in 3D objects [15]. One of the main issues that people face is the development of multi-material-based fabrication systems. Stereolithography technology can use several materials during a process; however, the process of replacing different types of polymers is very complicated and slow process [16]. Besides, there was some progress on multi-material inkjet-based systems, but they have a limited accuracy of printed objects [17]. In a similar work [18], the authors have emphasized that selective laser sintering has a good potential of using multiple powdered materials. However, most of the SLS 3D printers on the market are specialized in using a single powder.

Additionally, almost all the SLS 3D printers currently use a blade or a roller to deliver a thin layer of a single powdered material across the printing area. In another research [19], it was stated that this kind of roller or blade technique is not suitable for multi-material –based 3D printing. In another work [20], it was suggested to use a nozzle like powder sweeper that will be able to sweep several materials to their correct positions. In addition to that, the roller and nozzle-based powder delivering systems were suggested in this work. By considering their recommendation, it can be concluded that this method can be appropriate only for a single printing object, but it is hard to apply such kind of technique for mass production in industrial manufacturing. So, in a similar work [21], the conventional methods with some improvements in working principles were suggested. All of the suggested methods mentioned above can be used according to the requirements and accuracy of the printing object. Overall, the development of such technologies for SLS 3D printing, where multiple materials are used has a great potential to be an important manufacturing method for the future generation in additive manufacturing technology. There are also some restrictions and limitations in the mechanical properties of 3D printed objects by using a single material. Works [22], [23] and [24] highlight some important information about different types of polymers, thermoplastics and polymer nano-composites that can be used in SLS 3D printing with multiple materials.

### C. Monte Carlo Simulation Method

In the mechanical properties of materials often have fluctuations in a certain range. Such uncertainty in the values of properties can significantly affect the stochastic behavior of a material. Research shows that the change in material properties can create stress concentrations and various mechanical reactions [25]. Thus, in the studies of the mechanical behavior of materials, it is necessary to consider the directionality of mechanical properties. For example, the study of the material properties of graphene sheets with defects includes spatial changes in anisotropic elasticity [26]. The anisotropic elasticity tensor was described by random fields determined by Monte Carlo Simulation method (MCS). [25, 26, 27]. MCS is a method for estimating the value of an unknown quantity using the principles of inferential statistics. That is, the MCS treats all quantity uncertainties as a set of data from which values based on their probability distribution are used. In this study, the MCS method was used to consider changes in the constant elastic modulus of the proposed polymers. The various values of Young's modulus were collected from existing test results and material specifications and filled in the database. The data were tested for a probability distribution. Usually, the database is desired to have a normal distribution. However, it is not the only necessity. The gathered database for the polymers does not have the normal distribution. Therefore, simple occurrence probabilities are utilized for further investigation. Among the obtained data, the frequently occurring values were considered the most significant. In the proposed MCS method, the input value is a random number to characterize the probability and is used in calculations.

## III. DESIGN AND DEVELOPMENT

The GUI (Graphical User Interface) has been developed to facilitate the operation of the SLS printer which uses multi-materials to develop new composites. The whole interface is developed based on the “Rule of mixtures” configured by above mentioned Monte Carlo Simulation for material property determination. The “Rule of mixtures” is the micromechanics approach that used to predict some mechanical properties of the materials [4]. In Fig. 1, the first interface is demonstrated, which allows the user to select 2 to 3 materials having up to 5 variations of the mechanical property inputs with probabilities. The volume fraction of composite materials is also defined here. In Fig. 1, the manual tab of the GUI is shown. It has four columns; the first three columns illustrate the input parameters for three different materials and the fourth column describes the parameters that should be written. The first three columns contain the number of values of mechanical properties that need to be defined. Also, it asks for the value of the specific mechanical property as well as the probability of that property. The fourth column asks for parameters such as the number of random numbers to perform the Monte Carlo Simulation. It should be noted that the results of the Monte Carlo Simulation become more accurate with the increment of random numbers. Also, the fourth column asks for parameters like volume fraction of the first material and second materials (the volume fraction for the third material is not required because it can be calculated automatically by the software). Finally, to get the results, the “Calculate” button should be pressed. Also, values can either be entered directly to textboxes or imported from Excel table by using “Import from file”, as demonstrated in Figs. 2 and 3. The values should be formatted as in Fig. 2 to import the data, and the Excel file should be named “materials_data.xlsx” with up to 5 inputs per material, and import task can be done by pressing the “import” button.

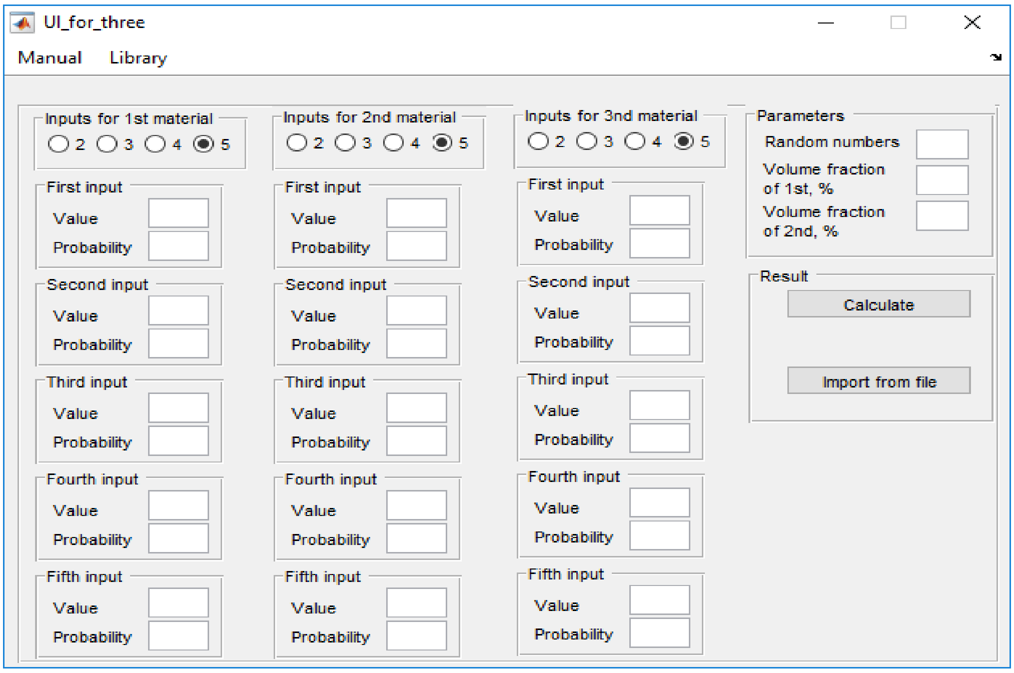
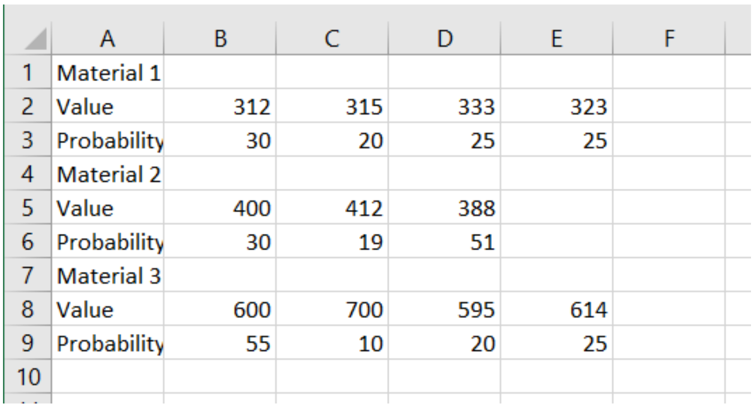
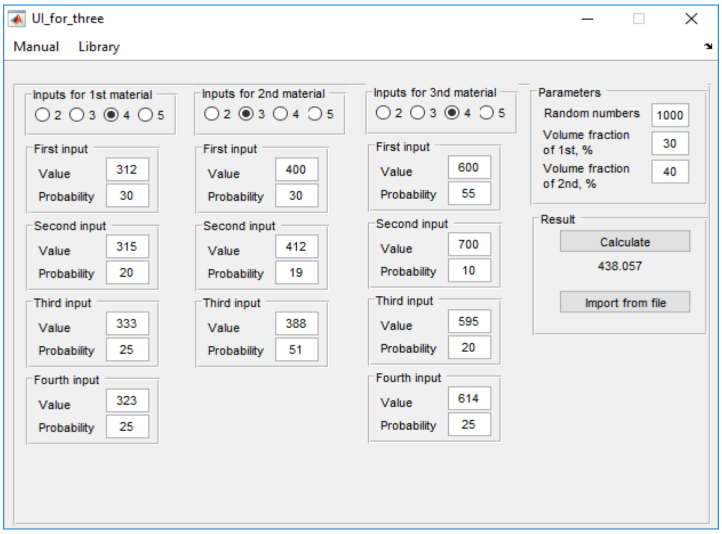


Figure 1. The first interface of GUI with manual input.



| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | Material 1 | | | | | |
| 2 | Value | 312 | 315 | 333 | 323 | |
| 3 | Probability | 30 | 20 | 25 | 25 | |
| 4 | Material 2 | | | | | |
| 5 | Value | 400 | 412 | 388 | | |
| 6 | Probability | 30 | 19 | 51 | | |
| 7 | Material 3 | | | | | |
| 8 | Value | 600 | 700 | 595 | 614 | |
| 9 | Probability | 55 | 10 | 20 | 25 | |
| 10 | | | | | | |

Figure 2. A set of required data to import.



Inputs for 1st material: ○ 2 ○ 3 ● 4 ○ 5
First input: Value 312, Probability 30
Second input: Value 315, Probability 20
Third input: Value 333, Probability 25
Fourth input: Value 323, Probability 25

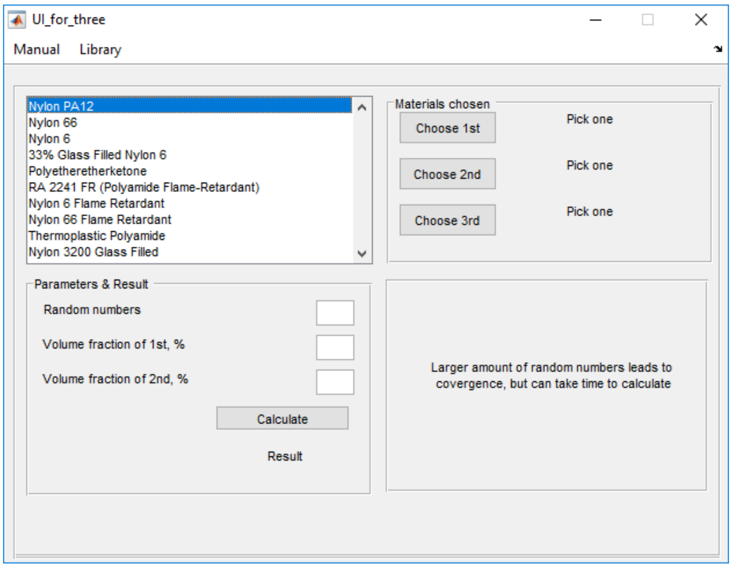
Inputs for 2nd material: ○ 2 ● 3 ○ 4 ○ 5
First input: Value 400, Probability 30
Second input: Value 412, Probability 19
Third input: Value 388, Probability 51

Inputs for 3nd material: ○ 2 ○ 3 ● 4 ○ 5
First input: Value 600, Probability 55
Second input: Value 700, Probability 10
Third input: Value 595, Probability 20
Fourth input: Value 614, Probability 25

Parameters
Random numbers: 1000
Volume fraction of 1st, %: 30
Volume fraction of 2nd, %: 40

Result: 438.057

Figure 3. The first interface of GUI after values was imported.



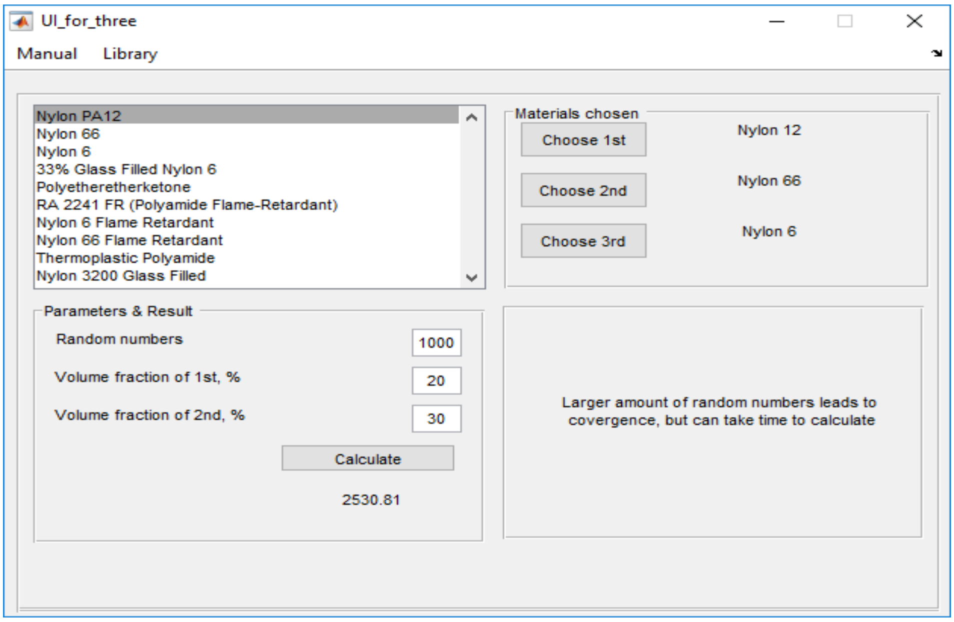
Nylon PA12
Nylon 66
Nylon 6
33% Glass Filled Nylon 6
Polyetheretherketone
RA 2241 FR (Polyamide Flame-Retardant)
Nylon 6 Flame Retardant
Nylon 66 Flame Retardant
Thermoplastic Polyamide
Nylon 3200 Glass Filled

Materials chosen
Choose 1st: Pick one
Choose 2nd: Pick one
Choose 3rd: Pick one

Parameters & Result
Random numbers:
Volume fraction of 1st, %:
Volume fraction of 2nd, %:
Result

Larger amount of random numbers leads to covergence, but can take time to calculate

Figure 4. The first interface of GUI with database input.



Nylon PA12
Nylon 66
Nylon 6
33% Glass Filled Nylon 6
Polyetheretherketone
RA 2241 FR (Polyamide Flame-Retardant)
Nylon 6 Flame Retardant
Nylon 66 Flame Retardant
Thermoplastic Polyamide
Nylon 3200 Glass Filled

Materials chosen
Choose 1st: Nylon 12
Choose 2nd: Nylon 66
Choose 3rd: Nylon 6

Parameters & Result
Random numbers: 1000
Volume fraction of 1st, %: 20
Volume fraction of 2nd, %: 30
2530.81

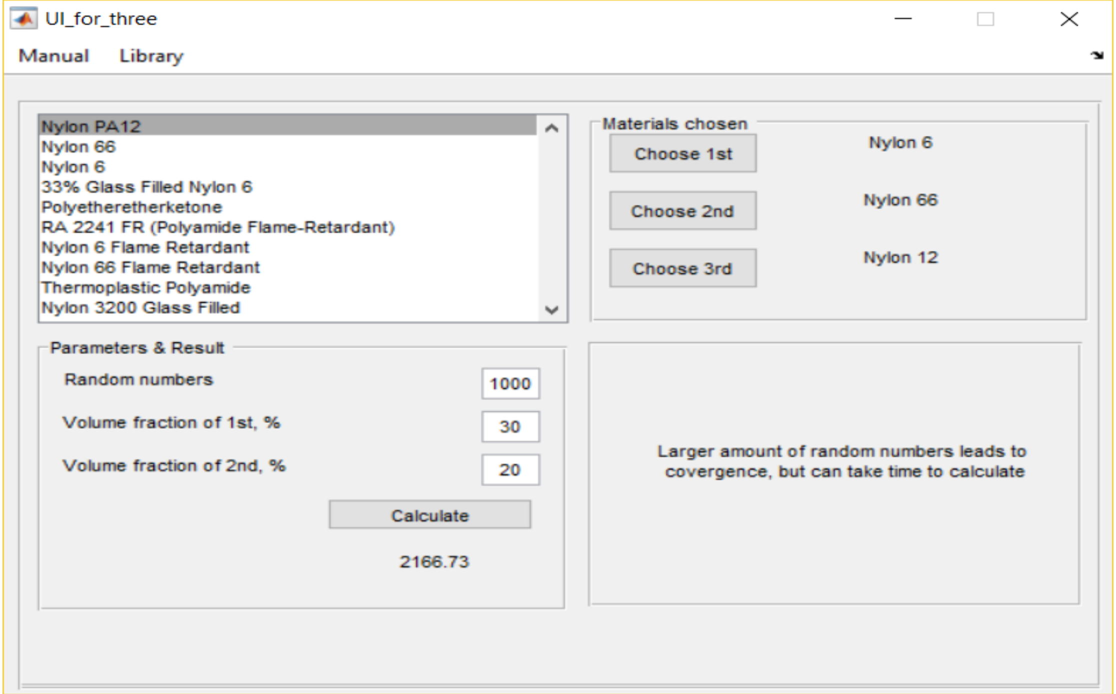
Larger amount of random numbers leads to covergence, but can take time to calculate

Figure 5. An example of calculation of the composite material using database interface.

Fig. 4 shows the GUI platform before the materials are selected. It can be seen from Fig. 5 that once the data is imported, the user can correct them, adjust some inputs for each material, set the desired amount of random number, volume fractions and calculate the results. Only the first two volume fractions are to be set; the third fraction is calculated automatically to fill to 100%. This type of data importing from the file can be helpful when there are lots of data to calculate and analyze because it takes less time to import data from Excel file compare to input each parameter separately. The second interface can be accessed from the top menu, by hovering over “Library” option. In Fig. 6, the second interface with the materials list is shown. It consists of 10 polymer materials with the collected database. Fig. 6 also illustrates the list of available polymers, which are Nylon 12 [5], Nylon 66 [10], Nylon 6 [6], 33% Glass Filled Nylon 6 [28], Polyetheretherketone [9], Polyamide Flame Retardant [7], Nylon 6 Flame Retardant [2], Nylon 66 Flame Retardant [3], Thermoplastic Polyamide [7] and Nylon 3200 Glass Filled [11]. From the materials list, up to three entries can be chosen together with the volume fractions for each. It is mentioned earlier that the types of materials which are going to be used should be selected first. Then the parameters such as the number of random numbers used for the Monte Carlo simulation should be defined, and the volume fractions for the first two materials should be written as well. The software will automatically calculate the volume fraction of the third material. Fig. 5 is an example of calculating the mechanical property of the composite consisting of Nylon 12, Nylon 66, and Nylon 6 in composition 20%, 30% and 50% respectively (third material’s fraction is not to be entered and is calculated automatically). Also, it should be mentioned that the Monte Carlo Simulation was performed for 1000 random numbers. Current GUI works by using an m-file with the same name to perform a Monte Carlo Simulation behind the scenes. It should be noted that the calculations and GUI were developed in MATLAB software. It has the functions such as importing data and exporting results to .txt or .xls files. The results obtained after the simulations can be used as data for obtaining the required mechanical properties by using several materials. The database consisting of several materials was developed in Microsoft Excel, which consists of sheets and tables. All the data such as the type of material and volume fractions are stored in tables.

## IV. Results and Discussion

The developed interface can be applied for both two and three composite materials property calculation. The volume fraction of the third material just should be defined as 0% to obtain a result for two materials. The number of iteration is required from the user as an input to the Monte Carlo Simulation. The constraint is the duration of the program execution, the larger number of iterations require longer duration for calculations. In Fig. 6, calculation of Young’s modulus is shown for Nylon 6, Nylon 66 and Nylon 12 polymers’ composite with the volume fraction of 30%, 20%, and 50% respectively, and with 1000 iterations. For this reason, three materials are chosen from the material list, as well as the volume fractions, and some iteration are defined at the corresponding inputs.



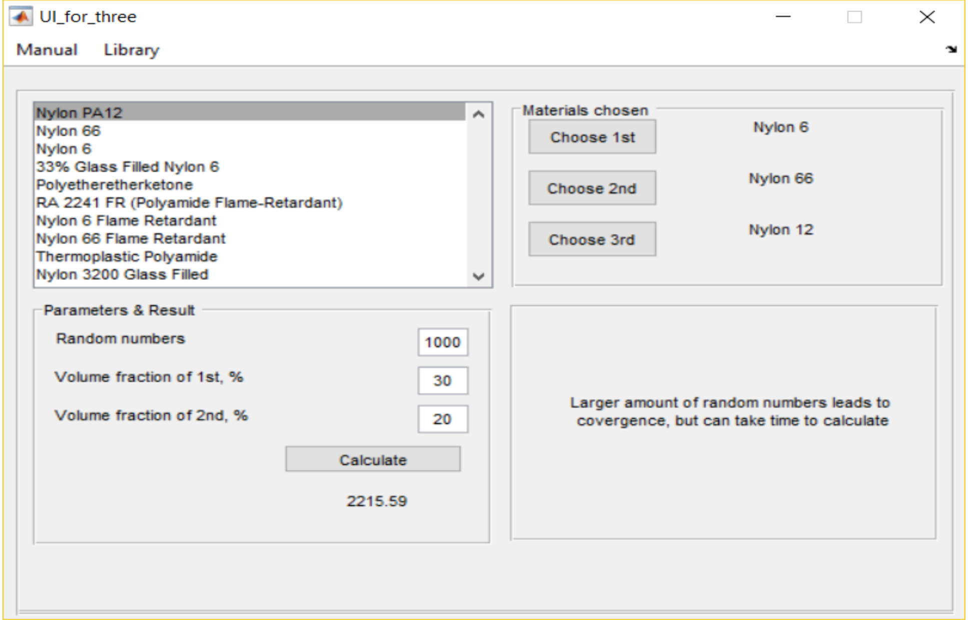
Nylon PA12
Nylon 66
Nylon 6
33% Glass Filled Nylon 6
Polyetheretherketone
RA 2241 FR (Polyamide Flame-Retardant)
Nylon 6 Flame Retardant
Nylon 66 Flame Retardant
Thermoplastic Polyamide
Nylon 3200 Glass Filled

Materials chosen
Choose 1st: Nylon 6
Choose 2nd: Nylon 66
Choose 3rd: Nylon 12

Parameters & Result
Random numbers: 1000
Volume fraction of 1st, %: 30
Volume fraction of 2nd, %: 20
2166.73

Larger amount of random numbers leads to covergence, but can take time to calculate

Figure 6. The first example of calculation of the composite material using 1000 iteration.



Nylon PA12
Nylon 66
Nylon 6
33% Glass Filled Nylon 6
Polyetheretherketone
RA 2241 FR (Polyamide Flame-Retardant)
Nylon 6 Flame Retardant
Nylon 66 Flame Retardant
Thermoplastic Polyamide
Nylon 3200 Glass Filled

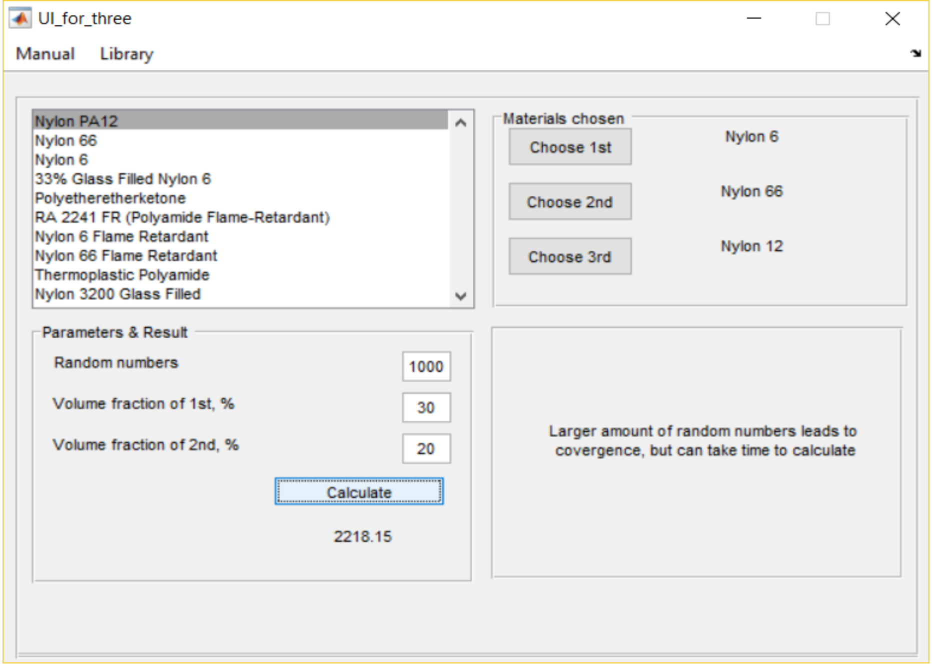
Choose 1st: Nylon 6
Choose 2nd: Nylon 66
Choose 3rd: Nylon 12

Random numbers: 1000
Volume fraction of 1st, %: 30
Volume fraction of 2nd, %: 20

2215.59

Larger amount of random numbers leads to covergence, but can take time to calculate

Figure 7. The second example of calculation of the composite material using 1000 iteration.



Nylon PA12
Nylon 66
Nylon 6
33% Glass Filled Nylon 6
Polyetheretherketone
RA 2241 FR (Polyamide Flame-Retardant)
Nylon 6 Flame Retardant
Nylon 66 Flame Retardant
Thermoplastic Polyamide
Nylon 3200 Glass Filled

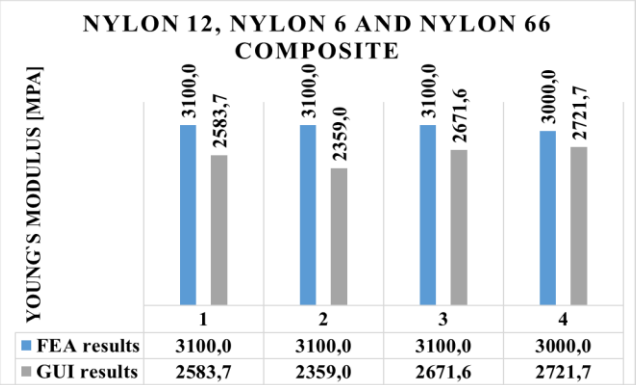
Choose 1st: Nylon 6
Choose 2nd: Nylon 66
Choose 3rd: Nylon 12

Random numbers: 1000
Volume fraction of 1st, %: 30
Volume fraction of 2nd, %: 20

2218.15

Larger amount of random numbers leads to covergence, but can take time to calculate

Figure 8. The third example of calculation of the composite materials using 1000 iteration.



|  | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| ■ FEA results | 3100,0 | 3100,0 | 3100,0 | 3000,0 |
| ■ GUI results | 2583,7 | 2359,0 | 2671,6 | 2721,7 |

Figure 9. FEA and GUI simulation results on composite materials consist of three materials.

TABLE I. THE MONTE CARLO SIMULATION RESULTS FOR THE DIFFERENT RANDOM NUMBERS.

| Attempt # | Number of random numbers | Result | Absolute error | Relative error in % |
|---|---|---|---|---|
| 1 | 1000 | 2166,73 | 24,07 | 1,11 |
| 2 | 1000 | 2215,59 | 24,79 | 1,12 |
| 3 | 1000 | 2218,15 | 27,35 | 1,23 |
| 4 | 10000 | 2195,51 | 4,71 | 0,21 |
| 5 | 10000 | 2196,13 | 5,33 | 0,24 |
| 6 | 10000 | 2195,89 | 5,09 | 0,23 |
| 7 | 50000 | 2192,11 | 1,31 | 0,06 |
| 8 | 50000 | 2192,53 | 1,73 | 0,08 |
| 9 | 50000 | 2191,87 | 1,07 | 0,05 |
| 10 | 1800000 | 2190,63 | 0,17 | 0,01 |
| 11 | 1800000 | 2190,91 | 0,11 | 0,01 |
| 12 | 1800000 | 2191,04 | 0,24 | 0,01 |

Since Monte Carlo Simulation is used to model the probability of different outcomes, and the important thing is that it should be analyzed to produce several identical iteration numbers, as well as for a different number of iterations. It is required to obtain more accurate results and thoroughly investigate the simulation. It is shown in Figs. 7 and 8 that for the same number of iteration, a slightly different value of Young's modulus for the same composite is obtained. There is no considerable difference between the results of a larger number of random numbers and the smaller number. However, as shown in Table I, for 180000 random numbers, the deviation is negligible. Therefore, it is desired to find a more appropriate number of random numbers. Thus, random numbers are considered and tested for three times. The results are shown in Table I in details highlighting the absolute and relative errors. To compare the results obtained from the Monte Carlo Simulation, the FEA is performed in ANSYS software. Tensile simulation is performed on specifically defined materials to obtain Young's modulus. The results are shown in Fig. 9 together with the results of Monte Carlo Simulation. It can be seen from Figs. 6, 7 and 8 that the results for 1000 iteration do not take too long to calculate. Some 1800000 number of calculations were performed to show the convergence. While taking around 10 minutes to calculate on powerful PC (Intel(R)Core (TM) i7-8750H CPU), results converge to be in 99.9% accuracy margin. Both the FEA and GUI simulations are performed on three materials composite to examine the interface, which are; Nylon 12, Nylon 6, and Nylon 66 with the equaled volume fraction for each material. Fig. 9 shows the impressive results as illustrated in the bar chart.

## V. CONCLUSIONS

The proper operation of multi-material SLS printing technology is essential. In the process of additive manufacturing, several factors play a crucial role to obtain suitable results, especially in uprising multi-material SLS printing. This paper proposed the special GUI interface in determining material properties and specific calculation techniques to solve the existing problems. Future study should focus on improving the interface and investigate other important parameters to be considered specifically in material selection and optimization.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## AUTHOR CONTRIBUTIONS

Md. Hazrat Ali obtained the grant and supervised the research project. All authors contributed equllay, and they approved the final version.

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