# Plastic additive manufacturing expert systems for small and medium automotives industries[*]

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## Abstract

*The additive manufacturing basic techniques are ideal for swiftly fabricating items and evaluating their functionality, making them ideal for fast prototyping. Lighting, automotive parts, consumer electronics as well as on-demand items are among the industries where it is most extensively used. Currently, there are various types of additive manufacturing processes and also various research of future processes. Each of the processes will give different results for the user's product as various parameters are involved. Therefore, the process selections can become problematic and challenging since additive manufacturing requires specification and knowledge in order to create a product with the most suitable additive manufacturing process. This research will serve the purpose of providing knowledge of the additive manufacturing process through an expert system. Expert systems have been widely used in providing solutions and to obtain the knowledge of certain information. This study will take on the challenge of gaining sufficient knowledge in additive manufacturing pertaining to its selections which will be presented through the set of an expert system in the software MATLAB that is being used. The methods of obtaining the information and providing solutions will be the key structure for this research. Therefore, the expected result for this research is to provide knowledge information on additive manufacturing process and also for its process selections that will be set up from the expert systems applications.*

***Keywords:** additive manufacturing, expert system, materials, MATLAB, selections*

## 1. Introduction

A knowledge-based expert system, often known as an Expert System (ES), is a computer software that can solve a problem by making its own decisions. ES is interested in developing a computational system that mimics intelligent human behavior. John McCarthy proposed AI, a machine that could reason, solve problems, and improve itself in the same way as humans do. It has crucial features like adaptive control, improved handling, and reusable ability of stored information. According to the sophistication, expert system performs actions such as perception, interpretation, reasoning, learning, communication, and decision-making in order to arrive at a solution for the given problem. From the inception ES system, various developments have been

done, which broaden its application to include pattern recognition, automation, computer vision, virtual reality, diagnosis, image processing, nonlinear control, robotics, automated reasoning, data mining, process planning, intelligent agent and control, manufacturing (Xu et al., 2011).

Additive manufacturing (AM) has previously been used to create complex parts in small batches. With the introduction of the latest production technologies that cover a larger range of materials, AM has recently gained traction. From the outcome, the quantity of products that are manufactured by using AM technology has risen (Attaran, 2017). Furthermore, the specialists that have expertise in the area and are familiar with the process technology are limited. Additive manufacturing has shown itself to be one of the most promising solutions for meeting market demands quickly. Metal additive manufacturing gives the same design freedom as well as appropriate materials and products for high-demanding requirements (Weller et al., 2015). Presently, AM is utilized to produce rocket engine components, artificial heart pumps, implants, cornea, bridges, beautiful jewelry, food items, automobile parts and houses (Kumar et al., 2021).

Even though there have been multiple research advances in usage of materials in AM technologies, optimal selection of AM process and its materials has not been thoroughly researched. As there are many possibilities of materials for any application as it comes from various types of range. AM process has multiple parameters which are difficult and hard to determine without the correct

specifications and its parameters and can cause defects on the products if selections do not match its parameters. The AM process should be able to operate and run smoothly only if each of its parameters is met accordingly. Each AM process provides different types of product structure depending on user preferences.

On the other hand, the process of setting up an expert system to provide information and knowledge on additive manufacturing process and its material selections is one of the problems in this research. This is because operating an expert system is not an easy task and therefore it may be confusing and challenging. An expert system needs to serve the purpose of helping the user to gain information easily. It needs to operate with the system to be easy to understand so that users will be able to benefit from the systems without any confusion or misunderstanding. The systems will require a flow of artificial intelligence from the software that is used.

Therefore, this study aims to create a pool of knowledge related to AM process to produce certain specified parts and build an expert system that utilizes certain artificial intelligence techniques to assist manufacturers in choosing the right materials for its AM process.

## 2. Research methodology
### 2.1. Research design

This research design was approached to a process of mind-mapping process. The process of obtaining the knowledge started from the process identification and its materials properties. From the properties, it was then separated into several types of parameters based on its importance. The parameters are being studied and identified for each of the materials. The data is collected and stored for the insertion of information in the expert systems.

The identities data, which will be collected and gathered in the expert systems. The data from the experts will be given accordingly based on the relevant information required for the additive manufacturing process and its parameters. Finally, the arrangement of an expert system is finalized and being set up after the process of researching through the literature review and understanding the way of an expert systems work (Figure 1).
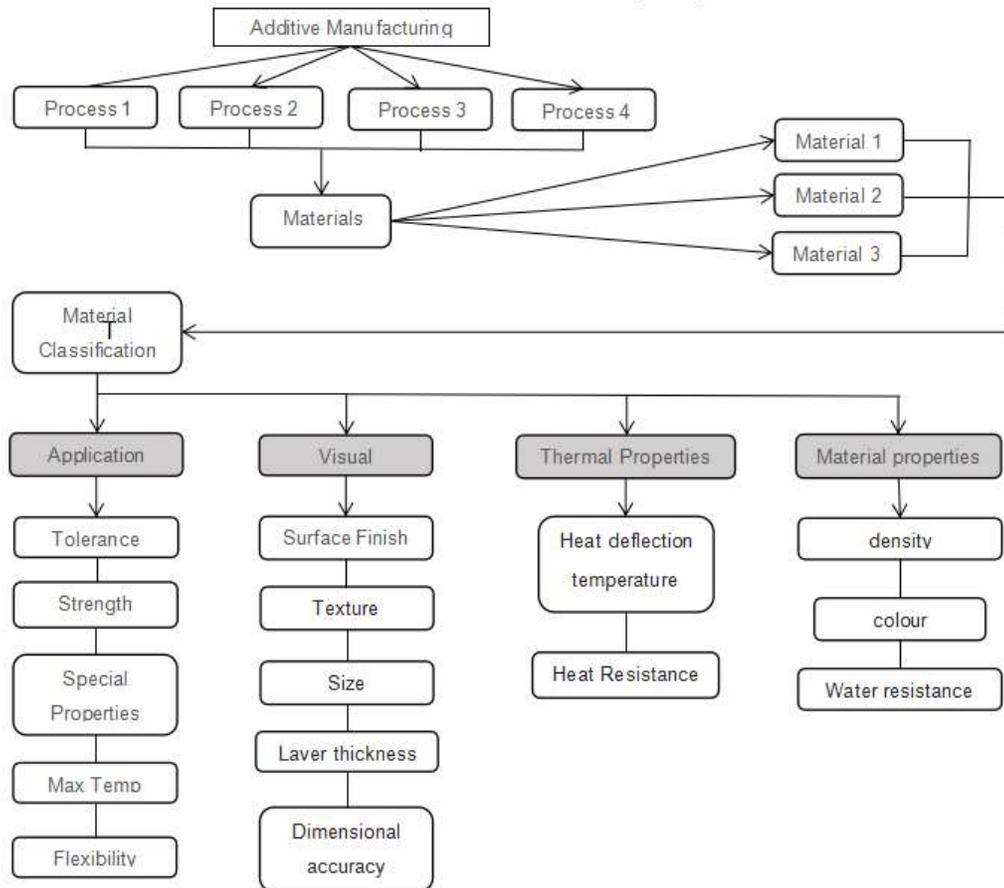


**Figure 1.** Process flowchart

## 2.2. Developing the system

The software that is used in this research will be the MATLAB software (Eitelman, 2003). Basically, the expert systems will be constructed in the software by using the If-Then rules. From the systems, the user will be greeted by the User Interface which connects the user to the expert systems. Then from the inference engine, rules will be applied based on the facts and knowledge of experts which was collected from the knowledge base.

Knowledge Base: it contains domain-specific and high-quality knowledge about the parameters of the AM process materials, all the needed info on the details of each parameter will be stored and collected precisely.

Inference: is where the facts and rules are placed to provide a correct and flawless solution. The inference will obtain the

previous rules and facts from the knowledge base about the AM process parameters.

User interface: Users will be entering the systems through this user interface; a set of questions will be provided, and the user will be answering according through the questions and data will be processed in the inference.

**2.3. Research flowchart**

Detailed and specific research needs to be done to provide the best arrangement of the materials and its AM process accordingly (Figure 2).
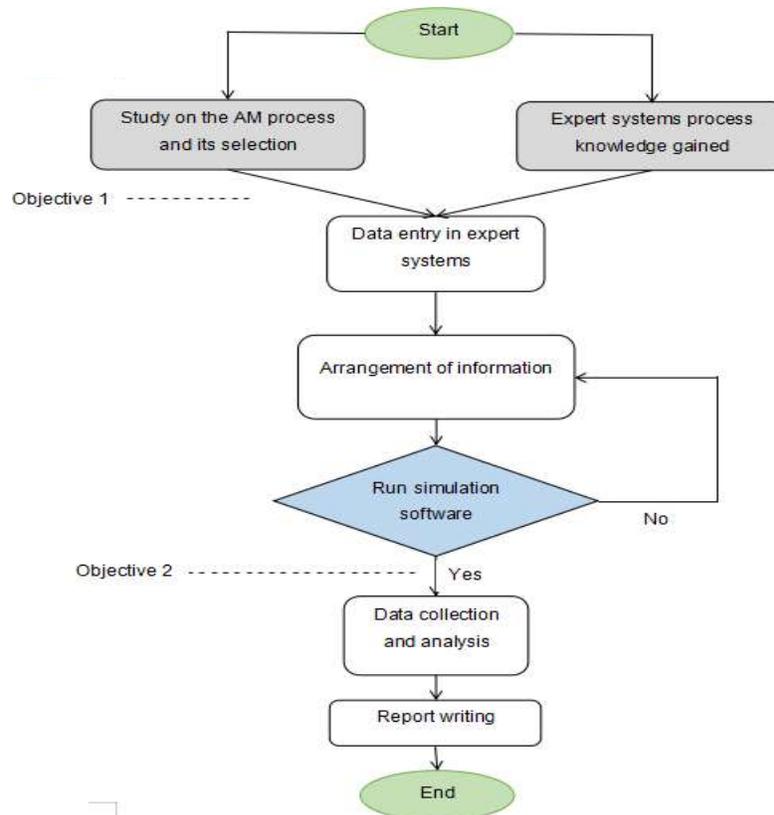


**Figure 2.** Research flowchart

Objective 1: create a pool of knowledge related to AM process to produce certain specified parts.

Objective 2: build an expert system that utilizes certain artificial intelligence techniques that can assist manufacturers in choosing the right materials for its AM process.

From past research, the properties of materials in AM process are being studied to understand each of the materials structure. Important factors when it comes to the materials are its parameters which consists of the functional applications and its visual appearance. Once the important factors of the materials have been specified accordingly, the materials with their matching characteristic should be chosen. As has been discussed in previous chapters, 3D printing relies on its type of materials where each of the materials has its own properties. Therefore, to have a smooth operation for the process, the selections of materials need to be critically

reviewed and understand which comes from its strength, flexibility or even its finishing, hardness and its cost. From this set of expertise, objective 1 would be able to be achieved.

The design of an expert system that provides the knowledge and arrangement breaks down through several processes. Each of these processes will have their own functionality which the systems that will be specified. From this process, knowledge will be acquired, and breakdown based on the preferences. This arrangement will be critical as it should be on track with the knowledge obtained. The user should be able to obtain enough information from this type of system as it is simple, easy, and reliable.

Once all the arrangement of the materials parameter has been selected, the type of analysis will be done to determine the final selection of the AM process materials. For this research, MATLAB software will be used to run the systems, which the programming software will be constructing a set of the system parameters through its coding.

## 2.4. AM process and material properties

From this study, identifications of materials and their characteristics are being identified based on their best characteristics. There are various characteristics that can play a factor in selecting the materials, however, there are a few characteristics such as strength, flexibility, hardness, elongation, finishing and cost which play a strong part for users to know. From this study, the knowledge about the materials and their individual definitions should be kept accordingly.

The graphical comparisons of a stress-strain curve and an elongation graph which is normally being referred are shown in Figure 3. Therefore, this data indicates that the necessary strength and its elongation will affect the product's final structure. After that, once the information has been processed, the structure of the expert systems needs to be classified accordingly. The information that is being shared with the expert systems needs to fill all the requirements so that users can understand and select accordingly based on their desired materials outcome.
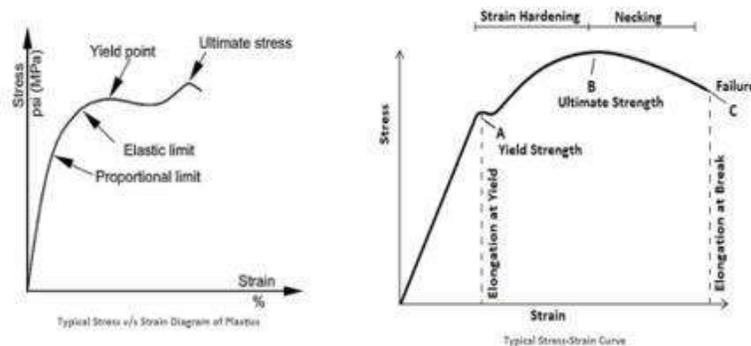


**Figure 3.** Tensile strength and yield elongation graph curve

## 2.5. Knowledge base

From each of the answer results will be determined and the relevant AM process will be saved. Therefore, from each of the results we can identify all the processes required. By using the If-Then rules the information will be processed accordingly.

IF the desired Tensile strength of the product is >28 and <43

Then the required material is ABS

IF the desired Yield Elongation of the products is >6 and <7

Then the required material is ASA

IF the desired Flexural Modulus is at <3.10 and >3.50

Then    the required material is PC

IF the desired Surface Finish is med

Then the required material is PLA and PC

The inference engines will be processing the systems and provide reasoning of the knowledge information in the knowledge base. The inference engines will also help in reducing the problems to find the solutions which will also provide the conclusions. This is for users to know what the details of the given questions are, and

which answer to choose for. Other selections of information will also be given accordingly based on other sets of parameters.

## 2.6. Data entry in expert system

The attribute list of the materials properties of tensile strength, yield elongation and flexural modulus are shown in Table 1. All of the following information is obtained from the research and background study on additive manufacturing properties.

The specification and properties of each material is being sourced from the knowledge base that is shown in Table 2. The information for each material is being compared and entered into the inference systems as this will properties information has been obtained through the mind-mapping concepts that is shown in research design.

**Table 1.** Attributes list of materials

| Material | Tensile Strength? | Yield Elongation? | Flexural Modulus? |
|---|---|---|---|
| ABS | >29.8 <43.0 | >1.7 <5.0 | >1.60 <2.40 |
| ASA | >47.0 <56.0 | >6 <7 | >1.50 <3.50 |
| PLA | >52.0<54.0 | >3.8 <5.0 | >3.8< |
| PC | >55.0 <77.0 | >3.10 <3.50 | >2.2 <2.5 |

**Table 2.** Specification and properties of each material

| Material | Hardness? | Surface Finish? | Material Cost? |
|---|---|---|---|
| ABS | 100 | Low | Low |
| ASA | 90 | High | Med |
| PLA | 75 | Med | Low |
| PC | >55.0 <77.0 | Med | High |

## 2.7. MATLAB simulation
### 2.7.1. Program flowchart

Simulations will be run in MATLAB

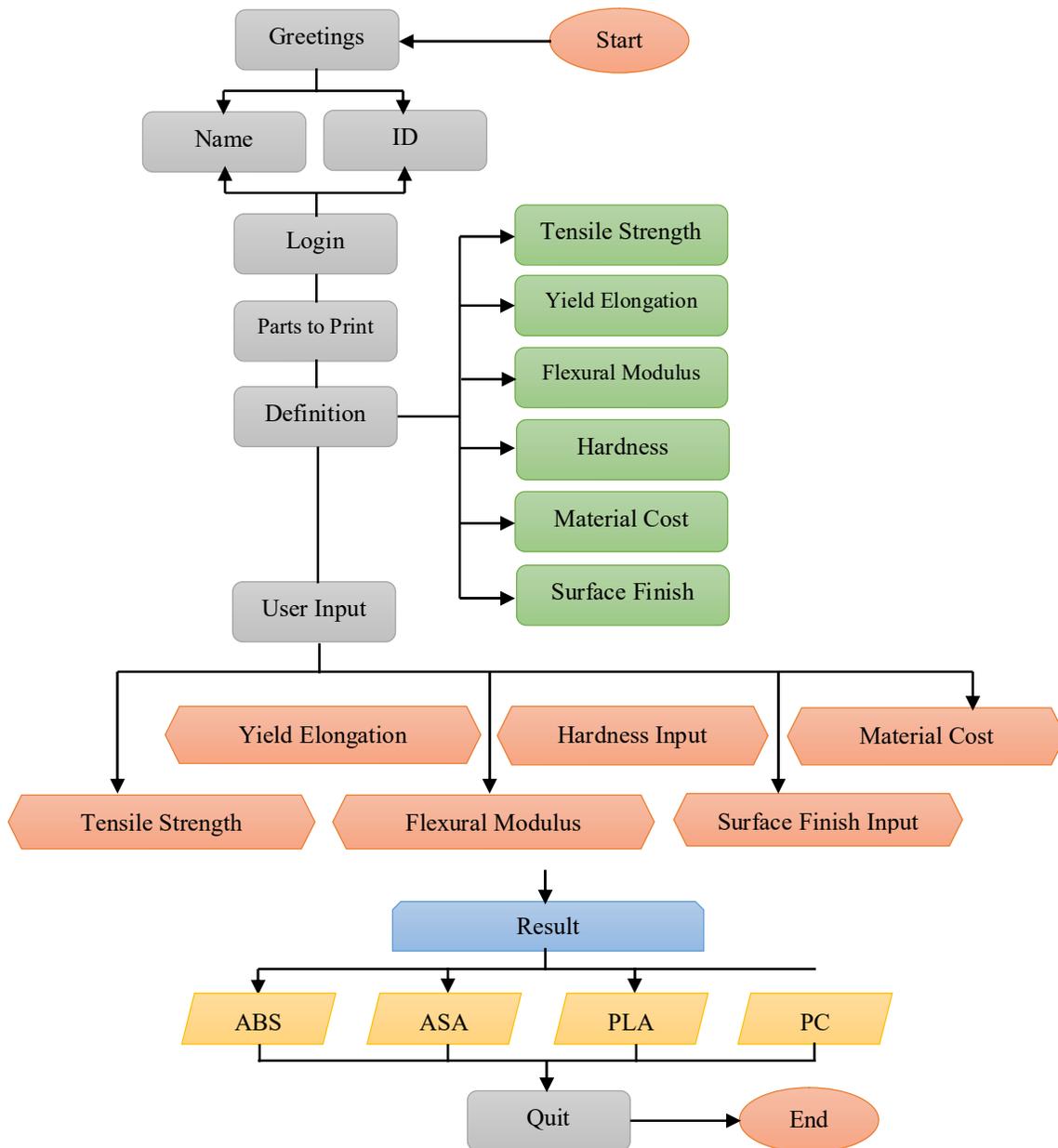software according to the following flowchart (Figure 4).

**Figure 4**. Simulation flowchart

### 2.7.2. Defining the menu items

The display menu of MATLAB program needs to be constructed and indicated correctly (Figure 5). The MATLAB program will be constructed from the editor which will then transferred to the command window. The coding needs to indicate what is the length of number that is required for the menu. Each coding will also describe the words and numbers for user input.

The structure of the program starts from the Menu Items. It defines how the system code is structured. The coding starts by indicating what menu items are to be displayed. The figure shows that selected display such name, greetings and quit are being indicated for the menu to pop up.

Next the attribute list is being listed based on the information that has been identified from our study. The list of attributes will be constructed by using point systems as we need to ensure that the coding constructions will match the answers by the user. Therefore, the table of attributes will be referred to and used inside the MATLAB program.
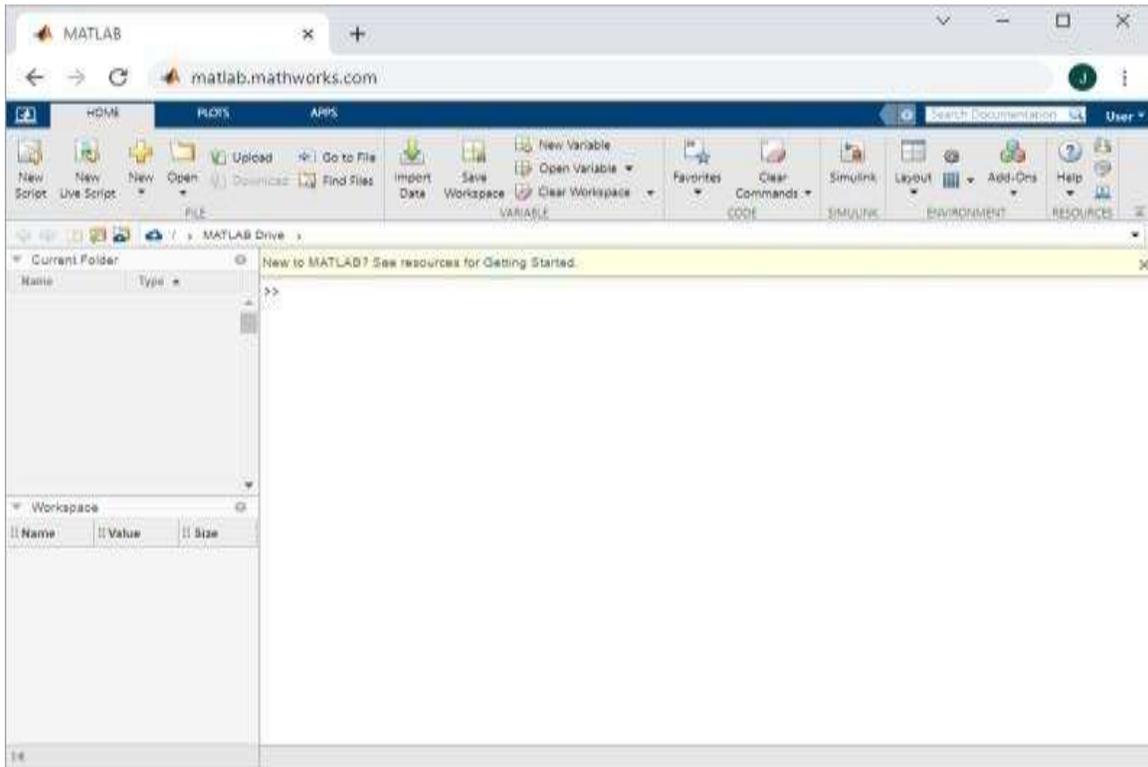


**Figure 5**. Command window

### 2.7.3. Defining user input

Defining user input means that user needs to know what to be selected and type in the program to achieve the results of the desired materials parameter. First, the users will require to Login to the program by inserting their name and their ID number, which once they have submitted both information the system will show the next information pertaining to the information about the materials characteristic information.

After that users can select on which type of characteristic information that they wanted to understand which then they will be provided with information. From there is where the knowledge based will takes place as the definition of each characteristic is classified.

### 2.7.4. Login credentials

The login credentials indicate that user must login before they proceed with the characteristic process (Figure 6). Firstly, the user will be prompted with a brief introduction about the title of the program before they can proceed. After that, the user will indicate their info which only then they will be prompted with the systems menu.

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**Figure 6**. Login credentials

### 2.7.5. Characteristics for user

The characteristics definition will help the user in understanding the selection of its value (Figure 7). User will be brief on what each of the characteristics meaning and the importance of the characteristics. From this selection, the user can select which characteristics that they require, and the definition will be shown.
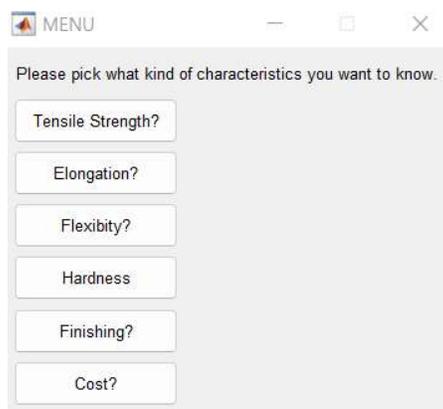


**Figure 7.** Characteristic definition

### 2.7.6. Material key properties

The material key properties section will provide users with the information about their selected material as it will help them in obtaining more knowledge before proceeding to print out their product (Figure 8). Not only for their selected material, user also will be able to know properties of other materials as well so they can re-evaluate their options accordingly.
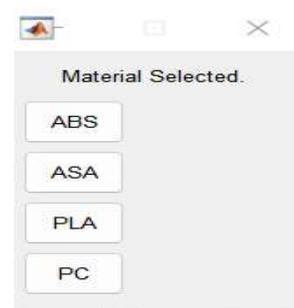


**Figure 8**. Material key properties

## 3. Results and Discussion
### 3.1. Results

The result that is shown is based on the simulation that is run in the MATLAB programming. Each of the structure and coding is designed to by referring to expert system structure and knowledge on additive manufacturing. The results obtained from a MATLAB program will depend on the specific code and inputs provided to the program. With the aid of the expert systems, the program is defined based on its rules to ensure smoothness of the program.

The decision table will attempt to put all the decisions into a matrix. The attributes and the conclusions and from the decision table it will shows how each of the information relates to each other. The decision table will be compiled, and final result will be shown to users.

The simulation No.1 will run accordingly once the user login and will ask for the user input (Figure 9). The user will then select each of the characteristics and its values. From the simulation, the values will be the key factor in determining the material. The values that have been selected will be stored inside the program and saved.

The final selection of the 3D print materials is displayed ABS based on the value identified by the user (Table 3). The desired selections will be based on the data and the user can proceed accordingly.

```
Command Window
  1.Login
  2.Parts to print
  3.Definition of each requirement
  4.Your requirement
  5.Quit
  Please choose the menu:4
  select tensile strength range from 27-77MPA: 28
  enter desired yield elongation percentage from 1.7-7% :2.5
  enter required flexural modulus range from 1.5-4.0 :3.4
  select your preferred hardness 75/80/90/100 : 90
  enter expected Surface finish low-med-high : med
  enter expected cost low/med/high :low
  Based on the user inputs, the recommended material is ABS
```

**Figure 9**. Simulation No.1

**Table 3.** Simulation No.1

| Questions Parameter | User Answers | Final Material Selection |
|---|---|---|
| Tensile Strength | 28Mpa | |
| Yield Elongation | 2.5% | |
| Flexural Modulus | 3.4 | |
| Hardness | 90 | ABS |
| Surface Finish | Medium | |
| Material Cost | Low | |

Similarly, the simulation No.2 will run accordingly once the user login and will ask for the user input (Figure 10). The final selection of the 3D print materials is displayed ASA based on the value identified by the user (Table 4). The desired selections will be based on the data and the user can proceed accordingly.

```
Command Window
  1.Parts to print
  2.Definition of each requirement
  3.Your requirement
  4.Quit
  Please choose the menu:3
  select tensile strength range from 27-77MPA: 77
  enter desired yield elongation percentage from 1.7-7% :6
  enter required flexural modulus range from 1.5-4.0 : 3.5
  select your preferred hardness 75/80/90/100 : 90
  enter expected Surface finish low-med-high : high
  enter expected cost low/med/high : med
  Based on the user inputs, the recommended material is ASA
```

**Figure 10**. Simulation No.2

**Table 4.** Simulation No.2

| Questions Parameter | User Answers | Final Material Selection |
|---|---|---|
| Tensile Strength | 77Mpa | |
| Yield Elongation | 6% | |
| Flexural Modulus | 3.5 | |
| Hardness | 90 | ASA |
| Surface Finish | High | |
| Material Cost | Medium | |

From the above result and its data. The experiment will be simulated, and the user will use the program to select its 3D print material. All the required input must be keyed in by the user so that the program will be able to run without any error. Users will have to understand the basic arrangement in 3D print in order to select the best type of materials for their products.

**3.2. Discussion**

The MATLAB programming language is a high-level "scripting" or "4th generation" language that is part of the commercial MATLAB software (Eitelman, 2003). There are many different materials that can be used for 3D printing, each with its own set of properties and advantages which the choice of material will depend on the specific properties and requirements of the finished product. For example, high-pressure jetting systems can only mix polymers with similar flowability and curing temperatures, while extrusion-based processes like FDM can only mix materials with similar melting temperatures (Vaezi et al., 2013). Others used graph theory and a matrix technique to construct an RP process selection methodology. The approach assigned an index to each RP process based on an RP process function generated from an RP process attributes digraph (Rao and Padmanabhan, 2007). After that, expert systems, according to are constructed in such a way that they can quickly detect aspects in an existing or prospective project that could have a detrimental impact on the project's outcome (Yazdi et al., 2019).

One author mentions Heuristic knowledge is less rigorous, more experienced, and more judgmental performance knowledge that is rarely articulated and mostly personal. In the field, it is the understanding of good practice, sound judgement, and plausible reasoning (Farid et al., 2002). A collection of major if-then rules was established to offer a good answer and recommendations are given from expert systems in order to develop a dependable inference engine. It is possible to see the if-then rules written in python syntax (Nicora et al., 2019).

For its first simulation by user, the best material that is recommended for the user will be the ABS as per its selection, the materials ABS has matched the most selected value of the user which comes from the tensile strength, material cost and its yield elongation. Even though other

properties value that was input does not fall under ABS classification, the selection will be ranked based on the most selected value thus making the ABS is the best one. Other materials also will be displayed if the user has selected their values according to the material specifications. Context provides all data generated during execution and inference provide analysis, backtracking and several other problem-solving methodologies which most expert systems are built around above components (Rich and Knight, 1991).

Basically, there are others type of programming that can be used such as PHYTON. PHYTON offers a high-level language which provides a better advantage in terms of teaching as for its good functionality (Van Rossum and Drake, 1995). However, MATLAB offers the best tools that are suitable for this project simulation.

For the second simulation by user, different materials have been recommended based on the program as it shows ASA as the best materials. As per its input value, the most selected value that matches the material is its flexural modulus, its Hardness and the material cost. While other properties values do not match the materials value, the system will rank based on the most matched thus it will program the system to display the recommended one. Therefore, from the simulation, users can proceed on printing their product parts as desired based on their value.

## 4. Conclusions

From the result and simulation, objective 1 is achieved as knowledge regards the additive manufacturing process and its parameters are defined according to its characteristics. The user will be able to gain information and knowledge that is beneficial to their use in their product development. Objective 2 was also achieved as expert systems were structured by using certain rules in MATLAB programming which is used to assist the users in choosing the materials for their 3D printed parts. This research is structured to obtain knowledge in the selections of additive manufacturing process and its material selections in the form of expert systems. As a conclusion, expert systems will be able to provide sufficient information and also operate accordingly based on the flow of the process, therefore the objectives of this research are achievable.

Additive manufacturing may have its own limitations, including the fact that it is generally limited to producing small- batch and prototype parts, rather than mass-produced products. It is also generally more expensive than traditional manufacturing methods, especially for large-scale production. However, the advantage that it has in terms of its capability to create various products with any desired requirements would surpass all the above limitations. Therefore, the view of product is label as a promising technology that has the potential to revolutionize the way products are designed and manufactured. It is important for businesses and manufacturers to carefully consider the benefits and limitations of additive manufacturing to determine if it is the right fit for their specific needs and requirements.

The specific characteristics of a plastic will depend on the intended application and the needs of the project. It is important

to carefully consider the properties and characteristics of different plastics to choose the one that is best suited for the intended application. The type of plastic used in 3D printing will depend on the specific needs and requirements of the project, as well as the capabilities of the 3D printer being used. It is important to carefully consider the properties and characteristics of different plastics to choose the one that is best suited for the intended application.

Expert systems are particularly useful for organizations that need to process large amounts of data or make complex decisions on a regular basis. They can help to improve the efficiency and effectiveness of business processes and allow organizations to tap into the knowledge and expertise of their employees in a more efficient and cost-effective way. Nonetheless, expert systems can be a valuable tool for organizations looking to tap into the knowledge and expertise of their employees and make more informed decisions. However, it is important to carefully consider the specific needs and requirements of the organization and to ensure that expert systems are used in a way that complements, rather than replaces, human expertise.

Finally, the combination of expert systems and additive manufacturing can help to improve the efficiency and effectiveness of the manufacturing process, enabling businesses to produce high-quality products more quickly and cost-effectively. Therefore, this project shows the use of both combinations which provide ease and information for users to gain knowledge that is related to additive manufacturing and its material. This study may have limitations that in turn can offer opportunity for future research. For future development, the expert system structure can be expanded to a larger and wider range of set-up and can be used in other types of additive manufacturing process. This will improve knowledge and create more reliable techniques in deciding or choosing its process and parameters. The expert systems also can be designed in other methods that can serve different purposes such as in diagnosing or even finding solutions which is quite helpful for industries.

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## Conflict of Interest

The authors declare no conflict of interest.

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