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Hybrid Manufacturing Optimization Using an Analytic Hierarchy Method for Multi-Objective

Dalia J. Al- Ibadi [1]
Daly_jb@yahoo.com
Ass.lec.
Dijlah university college

Hind B. Ali [2]
130047@uotechnology.edu.iq
Asst. Prof. Dr.
AL technology university

Engin S.Sansarci [3]
engine.sansarci@altinbas.edu.tr
Asst. Prof. Dr.
Altinbas university

ABSTRACT

This work presents a framework for integrating processes in hybrid manufacturing that utilizes the strengths of each process. This work focuses on hybrid methods such as "fused deposition modelling" and "CNC machining". The hybrid technique is built on a system that creates a framework for interrelationships, allowing effect and value to be understood and appraised. The analytic hierarchy process (AHP) organizes decision making, using what has been learned about the previous procedures to successfully component complexity management for effective design and manufacturing the most valuable element. The prime focus of this study is to improve a method for selecting process parameters, evaluating the mechanical and physical properties of specimens creating using the fused deposition modelling technique. Before utilizing FDM to create a product, a number of parameters must be established. The component orientation, infill pattern, fill density, layer thickness, printing speed, and shell thickness are some of these variables. There are certain outputs from the final component that can be noticed, examinations and measures. Some of these replies include the final product's dimensions and mechanical characteristics, such as its tensile strength, impact strength, and compression strength. In this study, the link between the process variables of a 3D printer employing fused deposition modelling (FDM) technology and a CNC machine for the output was examined. The substance used was PLA plastic, which was widely used in the sector. Knowing the connection between the parameters and the outcomes enables the production of the final product to satisfy user requirements. Responses were gauged and evaluated for dimensional correctness and product robustness. Dimensions of mechanical test specimens' gauge areas (tensile strength, impact strength, and compression strength) fabricate in comparison with the measurements specified by (ASTM 638-03, ISO 180), and (ASTM D695) correspondingly also served as a measure of dimension correctness. The analytic hierarchy process (AHP) to identify the operation parameters that have an effect on the mechanical and physical attributes of the specimens.

Keywords: Additive Manufacturing, Fused Deposition Method (FDM), The Hierarchical Analysis Process AHP, Mechanical Test.

INTRODUCTION

Three-dimensional (3D) printing involves building objects out of paper-thin layers using data from 3D CAD files. It is an extremely flexible technique for making beautifully crafted things out of materials like ceramics, metals, or polymers. Fused deposition modeling (FDM), one of the several types of 3D printers, is now the most commonly used and affordable technology. Which is better, quick prototyping or machining? Will likely hear a wide range of responses. They may be utilized in quite different settings, thus how could one compare? Rapid prototyping was replaced by additive manufacturing by ASTM (American Society for Testing and Materials) in 2009 according to D. Fisher and R. Hofmann, 2009, and T. Waggoner.

This marks a significant change in additive manufacturing's initial context of being used just for prototypes, opening for broader application. Thus, the context of additive manufacturing application has shifted, along with the domains in which it can be utilized. Another answer to the issue “which is better, fast prototyping or machining?” maybe one that is similar to "my silo." Because additive manufacturing (AM) and machining did not evolve jointly, they became independent fields, creating what may be referred to as several "silos" of knowledge. They use separate systems for process planning; additive manufacturing process planning is managed in AM software (e.g. CatalystEX, ZPrint, etc.) while machining process planning is organized and managed in separate computer aided manufacturing (CAM) software. Different materials are utilized in CNC (computer numerically controlled) machining and additive manufacturing (including fused deposition modeling, or FDM); each additive manufacturing technique has a constrained selection of materials that may be employed. For instance, FDM machines usually employ specific thermoplastic material that is exclusive to the machine and company and is packed in cartridges. On the other hand, a wide range of metallic and non-metallic materials may be CNC machined, and a large supply of production tools and materials is available. Different machine makers, control interfaces, and machine operators are required for the various technologies. These procedures and technologies function according to two different philosophies, namely addition and subtraction. The paper focuses on the mechanical properties of samples produced on CNC machines and 3D printing machines, as well as the capabilities and implementations of these capabilities. The goal of Rapid Prototyping is to incorporate the CNC machine into the Rapid Prototyping environment and study the usage of the Analytic Hierarchy Process (AHP) as a decision-making tool. In contrast to subtractive manufacturing, additive manufacturing (AM) uses solid, three-dimensional 3D printing and so-called quick prototypes are referred to as "AM." The primary concept behind this is a prototype that was created utilizing a 3D CAD design technology and can be built right away. It is also known as a method of layering materials to create components from 3D model data. A broad overview of 3D printing and CNC machines will be covered in this paper. Next, a more thorough introduction to fused deposition modeling will come after a review of the various 3D printing processes (FDM). Different process parameters factors influence the characteristics of RP components. The process parameters for the various RP component qualities can be improved. When surface roughness and strength are required, mechanical properties become critical in meeting standards. . Because physical and mechanical properties influence how workable components behave, it is important to investigate how various process parameters affect these attributes. AHP is accustomed to address the problem of multi-objective optimization .The outcome of the multi-objective problem is a solution set that comprises an optimum parameter solution that relates the impact, strength in compression and strength in tension.

Quite simply, the term “3D printing” also known as the method of creating items by stacking several, very thin layers of material known as "additive manufacturing." This literature review was conducted with consideration for the subsequent subjects of need identification since they are crucial to the issue this thesis investigates. Including "Analytic Hierarchy Process" (AHP) as being a philosophy and methodology of the work.

CANELLIDIS et al, 2009 studied the effect of build orientation affects element fabrication accuracy, cost, and time, making it a crucial fabrication parameter in layer manufacturing (LM)in this work he an automated decision-support system task for orientation selection is suggested. he suggested method employs multi-criteria optimization and genetic algorithms methods for determining a (near) ideal build Orientation for stereolithography-made items. Surface roughness, build time, and post-processing time are regarded as the primary criterion for optimization.

YE LI , JIAN ZHANG, 2013 employed a multi-sphere model for quick prototyping to optimize the construction direction across several variables. Each sphere is created by discretely and equitably to the area of a spherical Unit., and each one symbolizes the global directed space for one optimization criteria. Part height and volume deviation optimization criteria are used to show the proposed multi sphere model, based on genetic algorithms for rapid prototyping, Pareto optimization of construction direction is used. To show the conflicting impact from these two criteria, the Pareto front is also computed. Despite the fact that just two criteria are now evaluated at the last he suggested that different surfaces must be dealt with independently in the Pareto front.

THOMAS and GILBERT, S.W, 2014 explored verity in cost and time for various "additive manufacturing process", that the efficient use of a 3D printer envelope will reduce expenses of an (AM) product. The capacity to use up all of the construction area is another important efficiency expect, Other researchers looked at the manufacturing of individual components those who analyze The implications of the supply chain on inventories, transportation costs, and the risk of supply interruption are not examined in assemblies, but in THOMAS’s study indicates that materials make up a significant portion of the price of items made via additive manufacturing technology. Additive manufacturing has an impact on both production costs and how the finished product is used.

Rahim and Maiden, 2014 discussed the important decision-making criteria for introducing AM in the Malaysian automobile sector. The framework for making decisions was developed using the analytical hierarchy process (AHP) in order to evaluate the factors influencing the implementation of AM. According to the research, the primary influences on AM implementations include financial, technical, organizational, and design-related practices. The expense of the investment should be given the highest weight. Lastly, the knowledge provided in this paper may help a future user decide whether or not to adopt AM technology.

BASIC STEPS OF RP

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Hind B. Ali [2]
Engin sanasrci[3]

Layers of material are added to create the desired shape in RP. The majority of commercial RP systems build an object by adding one layer after another, the (figure 1) shows the steps in the process typically employed in an RP method.

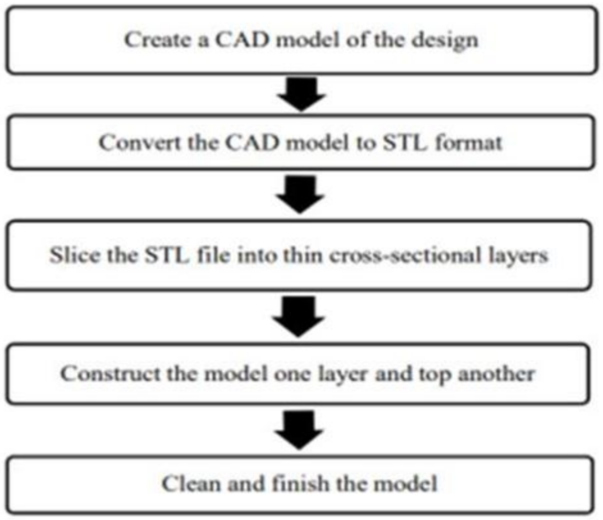


Fig.1.steps of rapid prototyping

FUSED DEPOSITION MODELING (FDM)

Fused filament fabrication, or 3D printing, is a type of additive manufacturing (AM) that comes under the category of material extrusion. FDM selectively deposits melted material along a preset path to construct components layer by layer. To create the finished physical items, filaments of thermoplastic polymers are used. .The PLA filament is heated to a molten state using a heating source. The filaments are then deposited on the component that is being built after being passed through the nozzle. Due to the fact that the material is thrown while it is still molten, it mixes with the surrounding material that has already been deposited. The head is subsequently moved into the XY plane and material is then deposited in accordance with the specifications of the part of the STL file [Smid, P., 2003].

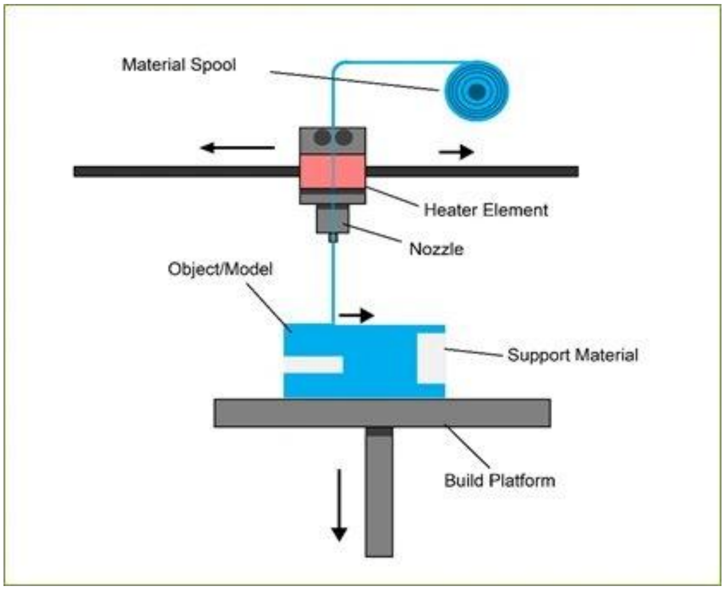


Fig.2**.** Fused Deposition Modeling (FDM)

CNC MACHINING

Contrarily to additive manufacturing, which dates back to the (1980s) with the development of stereolithography, machining (or material removal) has been around since the invention of CNC lathein 1700 years ago [P. Khamhong et al, 2019] , Cutting, abrasive processes (such as polishing), and complex machining processes are the usual divisions of machining (e.g. laser cutting). a. The Given categories of CNC machine tools are represented by

- Mills or machining centers.

- Lathes and turning centers.

- Drilling machines.

It is clear that additive manufacturing (FDM) and CNC machining are compatible technologies by examining their process and technological properties. FDM and CNC machining use quite different technologies and processes, which allows for a clear distinction between the procedures' advantages and disadvantages. For the most efficient outcome, a hybrid method combines the necessary design and production qualities with technological and process capabilities [J. Delgado, J. Ciurana, and C. A. Rodr´ıguez, 2012]. Samples were created in the 3D printer using a polymeric material, while in the CNC machine, a plate made in the 3D printer was utilized and sliced using the CNC machine to compare the mechanical properties of the two machines.

THE ANALYTIC HIERARCHY PROCESS

AHP One of the common helpful techniques for choosing projects, which are becoming increasingly important. It highlights the importance of the procedure a decision-maker introduces as well as the attempts to quantify relative priorities for a given set of alternatives on a ratio scale based on the decision-judgment and attempts to ensure the consistency of the comparison of alternatives in the decision-making process. Analytical Hierarchy Process (AHP) is helpful for assessing subjective criteria in the context of complicated multi-parameter options. AHP is one of the MCDA methods that use analytical principles based on the application of both mathematical analysis and psychological concepts according to AS1100, 1984.

EXPERIMENTAL WORK

In this work, two set of specimens were created, each with three samples. The first group of examples was created using a 3D printer, while the second group was created using a CNC machine. In this work, a comparison will be done between two sets of specimens created using different manufacturing process. The specimens were created using Soildwork software and subsequently sliced with Cura software; process settings must be defined Print speed was set to 60 mm/s, layer thickness was set to 0.25mm, shell thickness was set to 0.8 mm, infill density was set to 75% , infill pattern was honeycomb pattern, part orientation was set to 45˚, and nozzle dimension was set to 0.4 mm.. Mechanical and physical properties of Specimens were tested, including tensile, compression, and impact tests for mechanical properties and dimensional accuracy for physical properties. The printing machine used to create the specimens is an arçelik machine, the material that used in this work is Polylactic acid (PLA).stage of the experimental work plan is:

Phase 1- Specimens Design

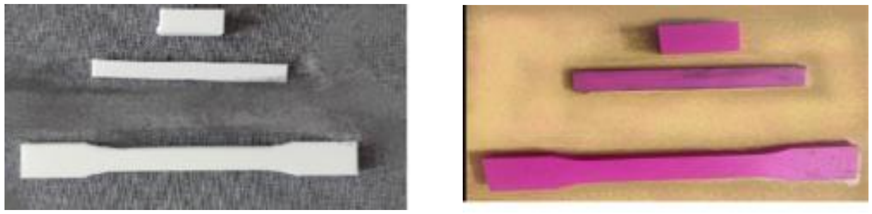
Phase 2- Slicing (Cura Software)

Phase3-Process Parameters Setting

Phase 4- Testing

SPECIMENS DESIGN

For each mechanical property test, specimens were designed using the solid works program, and the drawings were to be saved in Standard Triangle Language (STL) file format. The STL form's use is that CAD programs deal with.



FDM **CNC**

Fig. 3. CNC AND FDM specimens

SLICING (CURA SOFTWARE)

The STL file is downloaded and set up in Cura slicing program. The slicing software's purpose is to slice the sample into the needed number of layers. Process parameters can be defined by the slicing program. The software sends the code to the printer and regulates the temperature of the extrusion nozzle.

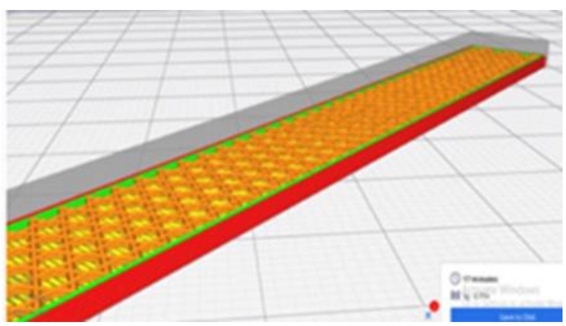


Fig. 4. specimens slicing(RED shill thickness ,Orange infill pattern,Green layer thickness)

PROCESS PARAMETERS SETTING

The printer settings have been modified to meet the needs of the material being used. The linked computer was used to control the item orientation, filament, print, and slicer parameters. The filament settings include the length of extruder for printing, and printer settings supplied total handle over bed temperature and filament extrusion parameters. The range of process parameters are summarized in Table (1). After confirming the settings, for filaments, settings slice set, printer axis, and extrusion then printing begin.

Table 1: Process Parameters with Their Levels and the temperature of nozzle 260° degree

Table 1**:** Process Parameters with Their Levels and the temperature of nozzle 260° degree

No.	Parameters	value
1	Printing speed (mm/s)	60%
2	Layer thickness (mm)	0.25mm
3	Shell thickness (mm)	0.8 mm
4	Infill density (%)	75%

FDM ARÇELIK MACHINE MATERIALS

prints using polylactic acid (PLA) which is a thermoplastic material that is highly used for Fused Deposition Modelling Acrylonitrile Butadiene Styrene (ABS) filament is more often used in 3D printing than PLA filament since ABS itself is more difficult to print with. PLA filament is Available in a variety of solid and transparent colours. Poly (lactic acid), sometimes known as PLA or simply polylactid, is a biodegradable thermoplastic composed of lactic acid. Because of the groups between the biopolymers, it is now more interesting for a variety of product applications because it can be easily replenished and broken down to nature. Due to its use in the pharmaceutical, healthcare, education, textile, food, and chemical sectors as well as the automotive and architectural industries, lactic acid is a multilateral substance. The organic acid was naturally created by fermentation or a number of other chemical processes

SPECIMENS TEST

In this work, we create two sets of PLA material samples using two different manufacturing processes, the first using FDM (Fused Deposition Modelling) and the second using a CNC machine. Where the two groups are examined and compared terms of mechanical properties, including impact strength, tensile strength, and compression strength.

Impact test

Izod Impact Test is an ISO180 standard method for determining material impact resistance Unnotched Izod Impact is a one-point test that evaluates a material's resistance to the swing pendulum's impact. Izod impact is defined as the potential energy required starting a fracture and maintaining it until the sample is completely fractured, Impact strength was computed by the division of impact energy in Joule by the area [Yuanbin Wang, 2011].

$$Impact\ Strength\ = \frac{Impact\ Energy\ (J)}{Cross - Section\ Area(m)} \quad (1)$$

Tensile test

Tensile tests have taken place in accordance with ASTM D638-03 at a cross head speed (strain rate) of (5 mm/min) and a load of (5 KN) until the specimen broke A tensile test's fundamental concept is to hold a sample of a material sandwiched in between two fittings, "grips." Given that the material's length and cross-sectional area are determined, weight is given to the one end of the material is grasped, while the other end is held. The load or force) is kept in increasing of while at the same time, the lengthening or shortening of the sample is evaluated. [Tahseen Fadhil Abbas, et al , 2022].

From the test on CNC sample, we calculate the ultimate tensile strength UTS as follow:

$$UTS = \frac{\sigma max}{\epsilon} \quad (2)$$

$$\sigma \max = \frac{f\ max}{A} \quad (3)$$

$$\sigma \text{ Fracture} = \frac{f\ f}{A} \quad (4)$$

Compression Test

Along with tensile and impact tests, One of the most common types of mechanical testing is compression testing. Compression tests are typically carried out by applying compressive pressure to a test specimen, which is frequently either cylindrical or cuboid in shape, using metal plate or other specific fixtures on a universal testing machine, in order to evaluate how a material will behave under crushing pressures. The characteristics determined during the test and shown as a stress-strain diagram include the material's, yield point, proportional limit, yield strength, elastic limit,for certain materials, compressive strength. Applied load was (25 kN) until the break of the specimen occurred.

Dimensional Accuracy

The term "dimensional accuracy" refers to an evaluation of how closely a given dimension matches a desired value. Accuracy refers to how closely the actual printed component matches the digital model when referring to 3D printed items. The ultimate quality is affected by a number of continuous variables that are present in both hardware and software. In order to get to the core of the problem, these factors should be addressed one at a time. Given that one factor influences and is impacted by others [14], it could seem overwhelming. Relative change in dimension was calculated using the following equation:

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Engin sanasrci[3]

$$\Delta x = \frac{x - x\ CAD}{x\text{CAD}} \quad (5)$$

Where, X is the measured value of length or width or thickness XCAD represents the respective CAD model value and ΔX stands for the relative change in X [D. Schuhmann, et al, 2022].

RUSTLES

A decision-making technique for hybrid manufacturing, CNC machining and additive manufacturing FDM Fused Deposition Modeling is generated using the analytic hierarchy process (AHP) In order to manage information complexity effectively and provide the most efficient production of a component; modularization is investigated and developed [K. Ransikarbum, et al, 2020]. The results in this work were obtained by using two groups of samples; one manufactured using FDM Fused Deposition Modeling and the other using a CNC machine, and studying the effect of process parameters for each manufacturing method on mechanical properties and identifying the most influencing criteria than others, The Hierarchical Analysis Process approach was used to find alternatives in order to select the best option from a set of options. This table 2 displays the results of the tests performed using the processing parameters for dimensional accuracy, Table3 represent the information necessary for decision-making.

Table 2: Information Available To the Decision Maker by compared the dimension in design and after manufacturing

Alternative	CRITERIA											
	Dimensional accuracy (mm)									**Impact strength (Mpa)**	**Compression strength (Mpa)**	**Ultimate tensile strength (Mpa)**
	Impact			**Compression**			**Tensile**					
	ΔL	**Δw**	**Δt**	**ΔL**	**Δw**	**Δt**	**ΔL**	**Δw**	**Δt**			
FDM	0.003	0	0.1	0.003	0.007	0.007	0.005	0	0	21.84	36	36
CNC	0.005	0	0.125	0.007	0.015	0.015	0.024	0.026	0.033	23.59	38	60

Table 3: Scale of Relative Importance shows Intensity of importance

Intensity of importance	**Definition**	**Explanation**
1	Equal importance	Two activates contribute equally to the object
3	Moderate importance of one over other	Experience and judgment slightly favour one activity over the other
5	Essential or strong importance	Experience and judgment strongly favours one activity over the other
7	Very strong importance	An activity is strongly favoured and its dominance demonstrated in importance
9	Extreme importance	The evidence favoring one activity over other of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgement	When compromise is needed

Table 4: Pairwise Comparison Matrix of mechanical properties for samples

	Dimensional Accuracy (mm)	**Impact Strength (Mpa)**	**Compressive Strength (Mpa)**	**Tensile Strength (Mpa)**
Dimensional Accuracy (mm)	1	3	5	7
Impact Strength (Mpa)	1/3	1	7	9
Compressive Strength (Mpa)	1/5	1/7	1	7
Tensile Strength (Mpa)	1/7	1/9	1/7	1
∑	1.64	4.25	13.14	24

Table 5: Calculated Weight Criteria for mechanical properties

	Dimensional Accuracy (mm)	**Impact Strength (Mpa)**	**Compressive Strength (Mpa)**	**Tensile Strength (Mpa)**	**W**
Dimensional Accuracy (mm)	0.6	0.7	0.38	0.29	1.97
Impact Strength (Mpa)	0.18	0.23	0.53	0.37	1.31
Compressive Strength (Mpa)	0.12	0.03	0.07	0.29	0.51
Tensile Strength (Mpa)	0.08	0.02	0.01	0.04	0.15
∑	0.98	0.98	0.99	0.99	3.94

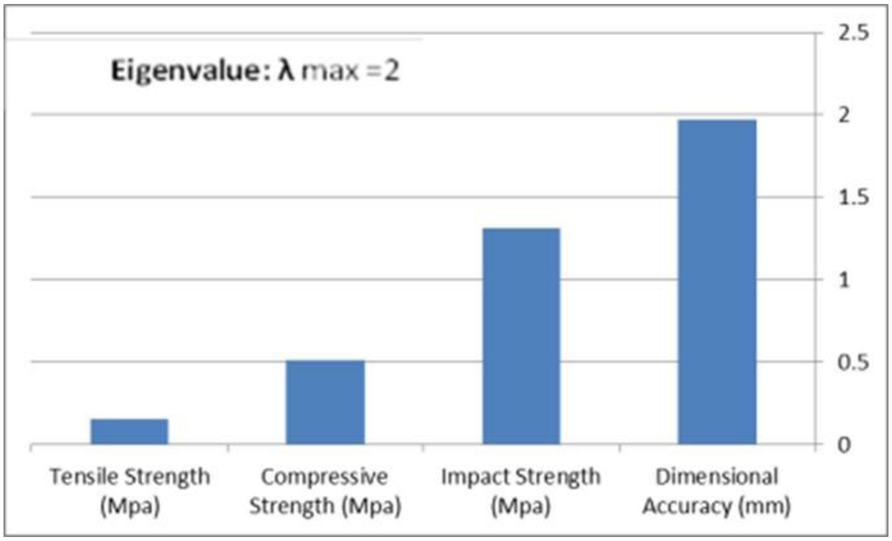

Fig.5. Weight of Criteria

Table 6: over all properties of weight of alternatives to finds which alternative is better

Alternatives	**Dimensional accuracy**	**Impact strength**	**Tensile strength**	**Compressin**	∑
FDM	1.460395	0.961479	0.75	0.972973	1.204374
CNC	0.539605	1.038521	1.25	1.027027	0.795626297
w	1.97	1.31	0.15	0.51	3.94

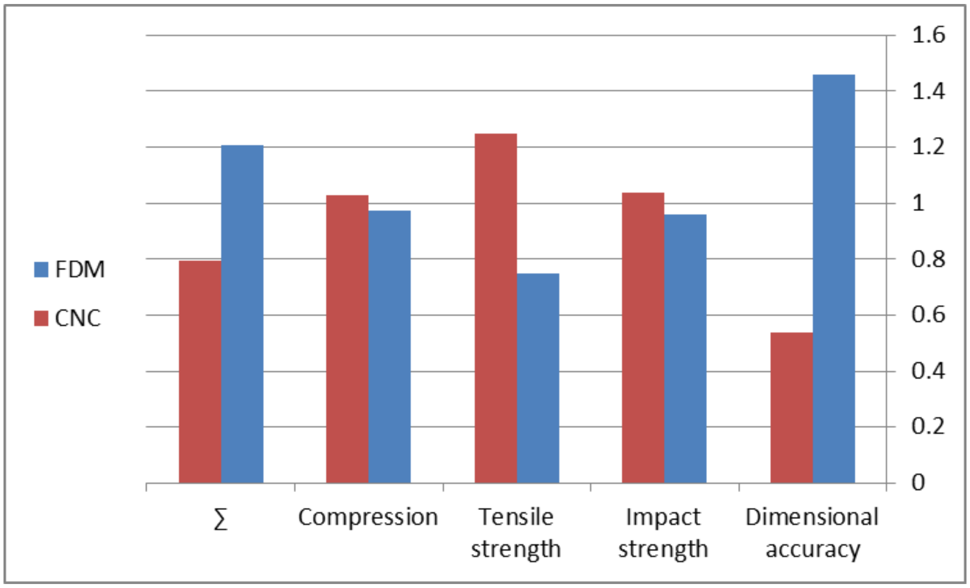

Fig.6.Over All Properties Of Alternatives

CONCLUSIONS

According to the findings in the previous chapter, the following important Conclusions were reached:

1. The technology behind additive manufacturing is unproven and yet in its youth. Products made using additive techniques reduce manufacturing costs and lead times. With this technique, intricate geometries may be modeled without the need for molds, CNC machines, or hand processing, and things can be made that would otherwise be impossible or very labor intensive to manufacture. This work presented a hybrid additive and subtractive approach to manufacture parts consisting of PLA materials.

2. In this research a couple of different manufacturing processes were used to create the CAD model that was then manufactured (FDM and CNC machine). The goal was to identify which of these methods would work best in a real situation. Four distinct criteria

were established for use in making such comparisons. The Analytic Hierarchy Process was employed for the final call (AHP method).

3. The first criteria weights were determined using a scale of relative relevance. After that, rankings of options were determined for each criteria. In the end, solutions were organized by a specified set of standards. Based on the weighted average of all three criteria, fused deposition modeling approach emerges on top, followed by CNC machine.

4. The AHP method's ability to assess both qualitative and quantitative data makes it a good fit for investigating hybrid production.

5. The relationship between mechanical properties (impact strength, compressive strength, and tensile strength) and process parameters (print speed, layer thickness, shell thickness, Infill density, and Part orientation) is positive; mechanical properties rise with different percentage increases in process parameters.

6. The optimal value for the specimens exposed to impact strength, compressive strength, and tensile strength, was found to be 45°.

7. Printing speed 60 mm/s, Layer thickness 0.25 mm, Shell thickness 0.8 mm, Infill density 75%, and Part orientation at 45° degree were the optimal variables of the PLA specimens for impact strength compressive strength and tensile strength were.

8. Evaluating the mechanical properties of each set of manufactured samples to find the optimum alternative using the AHP reveal that the FDM samples have the best mechanical properties. the Analytic Hierarchy Process for optimizing process parameters in both sample FDM and CNC. As a consequence of optimization process, the dimensional accuracy of FDM samples is greater than that of CNC samples with big length. Width and thickness. The mechanical properties finding of optimization technique demonstrate that the FDM sample has a higher value than the CNC samples. Dimensional accuracy was created by contrasting the measured dimensions (thickness, length, and width) of all printed mechanical test (tensile test, compression test, impact test) specimens with the standard tensile specimens as ASTM D638-03, compression specimens as ASTM D695, impact specimens as ISO180

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