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Laser Machining Machinability Index Using GTMA

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***Abstract*—Advanced machining techniques like laser beam machining are utilized for a variety of tasks like cutting, turning, milling, drilling, etc. LBM is dependent on a number of variables that affect the entire machining process. The efficiency, economy, and overall quality of the laser beam cutting process are determined by a wide variety of process parameters. The machinability of the work material being processed has an impact on all machining operations. As a result, the goal of this study is to assess the LBM's machinability index utilizing Graph Theory and a Matrix Approach. The study tries to identify various aspects of machinability and their relative weights in that regard. After determining the properties, a mathematical function will be created using the matrix method and graph theory. A visual representation of considering characteristics with their related interactions will be created as an attribute digraph. Matrix expression will be used to further represent this digraph. The permanent function calculation that yields the numerical values of the Machinability Index is arrived from this initial matrix. Additionally, in this paper a permanent machinability index for the proposed model is demonstrated.**

I. INTRODUCTION

A laser beam is a stream of singularly wavelength-focused, coherent light. Although the term "laser" is now widely used, its original meaning was "light amplification by stimulated emission of radiation." Many different types of lasers are employed in a variety of technological processes, such as welding and surgery. The orbits of the electrons inside an atom can alter when the atom is exposed to energy. Photons, tiny units of light, are released as a result. While photons in a regular light beam are released randomly, they are focused and more organized in a laser beam. In most cases, this is accomplished by a method known as stimulated emission, which occurs when photons emitted by one atom prompt other atoms to produce photons with the same wavelength. A massive chain reaction can be steadily built up until a laser beam is produced using mirrors, which are also found in most laser equipment. the various applications and techniques of LBM, what machinability is, and how it affects a machining operation's performance. The use of traditional machining techniques is constrained by the emergence of new engineering materials, demanding design specifications, intricate shapes, and unusually large workpieces. Thus, the need to create a few unconventional machining techniques called as advanced machining processes (AMPs) was identified. A coherent and amplified electro-magnetic radiation beam is referred to as a laser (light amplification by stimulated emission of radiation). One of the most popular thermal energy-based non-contact types of advanced machining processes, laser beam machining (LBM) can be utilized on a wide variety of materials. Finding out about Laser Beam Machining's machinability characteristics is crucial because it is the first step. The characteristics of machinability can be determined in a variety of ways, including through surveys, expert comments, surveys concerning laser beam machining, and other methods. There are several different characteristics of machinability for laser beam machining. By taking into account how important each attribute is for machining, the qualities can be divided and sorted. The aim of this paper is to list the characteristics of machinability for laser beam machining. to show an LBM digraph with the Machinability property.to create a Machinability Index and gauge the traits' relative relevance. Using the Machinability values, create a scale. The remaining content is arranged as follows. An overview of the literature is given in Section 2. The proposed methodology is shown in Section 3. The results and discussions and management insight are covered in Section 4. Section 5 provides the conclusion and suggestions for further study.

II. LITERATURE REVIEW

According to Sun et al. (2013), LBM is a special kind of machining that uses photothermal processes to separate materials by controlled fracture such as melt ejection and vaporization. Additionally, they came to the conclusion that the material's optical and thermophysical properties, as well as the laser beam's wavelength, power, focusing, and pulse frequency, had a significant impact on the cut quality and maximum cutting speed. The LBM is a good machining method for the micro elliptical profile in aluminum composite material, according to Senthil Kannan et al. (2019). The input parameters, i.e., power and scanning speed, are 3 kW and 50 mm/s, respectively, and are the closest dimensions to our desired dimensions of the shape that were acquired. The aforementioned parameters may be used in upcoming works to obtain a better profile shape while using laser beam machining. The TOPSIS approach, one of many optimisation techniques, can be used to choose the right parameter and obtain better results. The LBM laser parameters (such as laser power, wavelength, mode of operation), material parameters (such as type, thickness), and process parameters (such as feed rate, focal plane position, frequency, energy, pulse duration, assist gas type, and pressure) were all mentioned by Dubey et al. in their 2007 paper. The creation of microcracks and dross adhesion, as well as HAZ, kerf or hole taper, surface roughness, and recast layer, are essential performance variables of importance for the LBM investigation. The authors also claimed that a variety of process parameters that affect the laser beam cutting process' efficiency, economy, and overall process quality. Hossain et al. (2014) found that a number of laser, workpiece material, and process-related characteristics, including laser power, laser wavelength, mode of operation, material type and thickness, feed rate, etc., had an impact on LBM quality. Minimised HAZ, taper recast layer, micro fractures, dross adhesion, and smooth surface roughness are all advantageous quality traits of LBM. Therefore, it was determined that a thorough understanding of Laser Machining phenomena was necessary. As a result, extensive modelling and simulation of LBM were done in order to make accurate predictions for these properties. According to Barge et al. (2019), surface reflectance is mostly influenced by surface roughness and laser wavelengths. The wavelength increases with increasing reflectivity, which results in a smaller absorption. The effect of temperature on wavelength absorption and reflection. The absorption rate increases as a material's temperature rises. However, the wavelength is the primary factor that influences absorption or reflection. GRA method is less complicated than Taguchi method as a result of the weighing element for various quality requirements. The focal point might be found on the work piece surface, inside the work piece, or underneath the work piece, depending on the material that needs to be cut. With an increase in laser power, the HAZ breadth widens. Titanium alloy (Ti3Al2.5V) is machined using a CO_2 laser beam in Samson et al.'s (2019) work.

Based on its uses in high-pressure turbines and the aerospace industry, among others, titanium alloy is chosen. To obtain the best values of the response parameters, such as the rate of material removal and surface roughness, the main input variables, such as laser power, gas pressure, cutting speed, and focal point, were appropriately modified. Taguchi-Grey analysis is used to optimise these machining parameters. In their study, Rao et al. (2001) recommended an approach based on digraph and matrix methods for evaluating the machinability of work materials for a particular machining operation. Any type of metal cutting operation can be performed with this approach, which is universal in nature. The suggested approach evaluates the machinability of work materials correctly and thoroughly by concurrently taking into account all of the criteria, in contrast to existing methods that only use one of the machinability assessment criteria. The suggested method identifies and takes into account the interrelationships between machinability attributes for a certain machining operation. For a certain machining operation, the suggested global machinability index assesses and ranks work materials. Additionally, the suggested approach aids in choosing the appropriate work-tool combination for a specific machining task. A graph theory matrix technique was offered by Geetha and Sekhar et al. (2016) as a method for determining the ideal configuration of operational parameters for a diesel engine. Depending on factors such as brake power, brake-specific fuel consumption, and brake thermal efficiency, among others, that affect engine performance. based on emission factors such as carbon dioxide, carbon monoxide, hydrocarbons, and nitric oxide. Graph theory and matrix method-based approach is proposed and validated for the machinability evaluation of titanium work material in ultrasonic machining, according to Ravi et al. (2015). By taking into account three key machinability qualities, their study's experimental run produced the highest permanent machinability index result. The outcome demonstrated that silicon carbide as an abrasive, fine grit size (mesh 500), and moderate level of power rating (300 W) are used in titanium as a tool material with machinability index. This approach is better suited for many machining applications due to its adaptability. A approach based on the digraph and matrix method is proposed by Jangra et al. (2011) to assess the machinability of tungsten carbide in terms of the rate of material removal during electrical discharge machining. Several theoretical, experimental, and AI-based methodologies were used for the optimization and modelling of LBM by its numerous process parameters, and each of these methods produced the necessary results and values that we may use when operating Laser Beam Machining. But it was discovered that a number of parameters and their impacts on the machinability are crucial for the evaluation of the machinability of work materials in LBM. Therefore, a scientific or mathematical instrument that can analyze the effects of many parameters as well as their impact on machinability is required. As a result, the GTMA technique was suggested, which offers a precise answer to the problem raised above because it takes into account relative importance.

III. PROPOSED METHODOLOGY

Here, the emphasis is on a technique based on graph theory. The process used to determine the qualities was based on an expert survey. The important data about each attribute and how they relate to one another was gathered. The main instrument used to gather all the data was three different sets of surveys. Despite the limited availability of LBM, we were able to obtain the essential information from the side of the experts. The second and third surveys only needed a small number of expert approaches, but the first survey was about shortlisting, which was crucial, and a significant number of expert opinions were considered. The proposed methodology is shown in figure 1

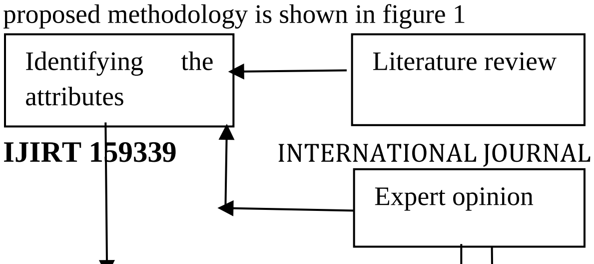

Figure 1
Proposed methodology

The influence of each attribute and its qualitative measures were then determined by conducting the final survey, followed by the formation of an SSIM chart to show the interdependencies. The primary component of the GTMA technique, which aids in the creation of the permanent function and attribute digraph, is the attribute. Therefore, this methodology uses graph theory and the matrix method to evaluate the machinability of work materials for a certain machining operation. We compile all the survey data, create an attribute digraph using GTMA, then use MATLAB to assess the machinability index.

Identification of attributes: Here, the machinability attributes were discovered by a thorough literature research that included journals based on LBM and their modelling. The optimization of factors in laser machining required the study and modelling of a number of process and performance parameters. The majority of studies concentrated on a particular set of variables and how they affected laser machining. And based on our investigation, it was determined that it was appropriate for inclusion in the calculation of the machinability index. As a result, we were able to identify 15 attributes from the literature review that demonstrated the significance of laser machining's machinability. As follows: 1. Laser power, Cutting speed, Assist gas type and pressure, Nozzle configuration, Focal setting, Material removal rate, Surface roughness, Pulse frequency, Pulse width, Temperature distribution, Kerf width and taper, Stand of distance, HAZ, Pulse duration, Thickness of workpiece. We were able to determine 15 criteria from the initial methodology that we would utilise to evaluate the machinability of LBM. Each of the chosen parameters has its own unique qualities and effects on laser machining. However, the study is merely based on a survey of the literature; there is no actual examination of how these characteristics are affecting laser machining, whether they are important or not, or whether they are a crucial process parameter or not. So it is determined by performing another survey on the rate of influence of these parameters on LBM that the chosen attributes have value in laser machining and are not employed only in a certain or special time. To narrow down the attributes, a thorough survey of specialists and the manufacturing side was done. To that end, a survey form with questions that are easy to complete and allow for rating the attributes on a five-point scale was created. The 15 features that we chose were included to the survey form, and respondents were asked to score each one on a five-point scale to indicate how much it affected or influenced the performance of laser machining. According to the survey, 8 characteristics were shown to have a significant impact on laser machining performance. We arrived at that by taking into account the characteristics that received responses on a five-point scale ranging from "3" to "5", which signifies "moderate" to "very high." The obtained attributes were found to be repeated and were used mostly in many journals. The shortlisted attributes are as follows:

1. Laser Power [LP]
2. Focal Setting [FS]
3. Pulse Frequency [PF]
4. Pulse Width [PW]
5. Stand of Distance [SD]
6. Pulse Duration [PD]
7. Thickness of Workpiece [TW]
8. Surface Reflectivity [SR]

It is best to seek the advice of academic and professional experts when determining the specifics of the contextual relationships between the variables. These academic and industrial professionals ought to be knowledgeable about the issue at hand. An ‘influence’ or 'leads to' type contextual relationship must be selected in order to analyse the components. This indicates that one factor affects another. This serves as the foundation for the development of the contextual relationship between the indicated components. Based on pairwise comparison of the variables and the contextual relationship, a structural self-interaction matrix (SSIM) is created as shown in figure 2.

	SR	TW	PD	SD	PW	PF	FS
LP	D	B	A	C	D	D	B
FS	D	D	D	B	D	D	
PF	D	D	C	D	C		
PW	D	D	C	D			
SD	C	D	D				
PD	D	D					
TW	D						

Figure 2

Structural self-interaction matrix (SSIM)

The SSIM graphic shows how different attributes are related to one another, which we can use for further study. However, we require the values or outcomes to be in matrix form in order to generate the attribute digraph. Thus, the creation of an initial reachability matrix using SSIM is the following step. Next we can create a binary matrix (see table 1)and an attribute digraph for further calculations to determine interdependencies. Table 1

Table 1

Initial Binary matrix

Sl. no	LP	FS	PF	PW	SD	PD	TW	SR
LP	1	1	0	0	1	0	1	0
FS	0	1	0	0	1	0	0	0
PF	0	0	1	1	0	1	0	0
PW	0	0	1	1	0	0	0	0
SD	1	0	0	0	1	0	0	1
PD	1	0	1	0	0	1	0	0
TW	0	0	0	0	0	0	1	0
SR	0	0	0	0	1	0	0	1

To do that, we introduce an SSIM chart and conduct a second expert survey. The mathematical model created using a graph theoretic method takes into account both the qualities' individual contributions and the degree of interdependence among them. For modelling and visual analysis, digraph (Universal machinability attribute digraph) representation is helpful as shown in figure 3. The digraph model can be examined using matrix representation. The system is characterized by constant function. The permanent function index is a distinct number that can be used for comparison, rating, and choosing the best possible combination. In order to offer graph theory and a matrix-based method for the analysis of machinability for laser machining, this article has two objectives.

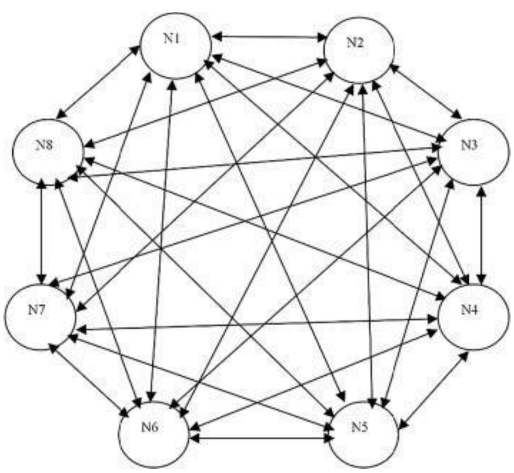

Figure 3

Universal machinability attribute digraph

For a quick visual evaluation, the attributes digraph provides a graphical depiction of the qualities and their relative value. An approach using graphics or pictures can be used to show how different qualities interact. A digraph is used to show the interdependencies between the variables that impact machinability in terms of edges and nodes. The machinability characteristics are represented by nodes, and their relative relevance is represented by edges. For the machining operation, the number of nodes taken into account is equal to the number of machinability attributes taken into account. Digraph and matrix representations both have variable node counts, therefore none is truly unique. An everlasting function of the matrix VPMMI is suggested in order to create a distinctive representation. A common matrix function used in combinatorial mathematics is called permanent. The permanent machinability function is known as the permanent of this matrix Z, or per (Z). For the purposes of this work, machinability evaluation represents the machinability characteristics of numerous experimental runs. Additionally, because there is no negative connotation in the expression, this strategy leads to the prevention of any information loss. We can find the permanent using Ryser's technique for that o code is developed in MATLAB.

Permanent of matrices and Machinability index: The Ryser's algorithm helped in converting the matrix to a function that can be implemented in MATLAB software. Each of the matrix i.e., minimum, maximum and reviewed matrices are added separately to the software to a single machinability index value or permanent function in numerical form. From the calculation of the matrix, we obtained the value for the minimum, reviewed and maximum threshold values. The result obtained was satisfactory. The obtained values were quite high. Therefore, in order to use these values in a practical point of view, the (ln)e values were taken and the values obtained showed that the material taken for GTMA method was found to be machinable.

The values obtained were as follows;

1. Lowest threshold value : 4.605
2. Reviewed/ Obtained value : 7.887
3. Highest threshold value : 10.631

Thus, from the calculated values we can construct a machinability index scale which will show the lowest, highest threshold values and machinable values. Low Mach inability Index Scale High

Inferences from the scale 4.605 Least threshold value 7.887 Evaluated value/

machinable value 10.631 Highest threshold value (See Figure 5).

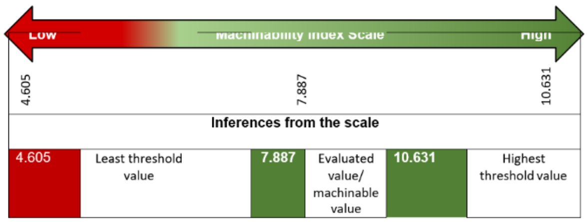

Figure 4 Machinability Index Scale

IV. RESULTS AND DISCUSSION

The aforementioned outcome led to the conclusion that the material was discovered to be machinable. The lowest and highest threshold values were 4.605 and 10.631, respectively. It was discovered that the number we arrived at from our evaluated values was 7.887, which was higher than 7.618, indicating that it is machinable. Calculating the permanent and comparing it to the scale we created will allow you to determine the machinability of any material. The important thing to note at this point is that all of the work we did above—literature review, attribute expert advice, calculation of the minimum, maximum, and reviewed values—was based on theoretical analysis, which involved reading numerous journals and papers and using mathematical techniques like MATLAB and GTMA. Therefore, as a future scope regarding this analysis, experimental approaches can be done for the calculation of machinability Index of Laser Beam Machining (LBM).

V CONCLUSIONS

There are several different characteristics of machinability for laser beam machining. By taking into account how important each attribute is for machining, the qualities can be divided and sorted. The aim of this paper is to list the characteristics of machinability for laser beam machining. to show an LBM digraph with the Machinability property.to create a Machinability Index and gauge the traits' relative relevance. Thus, from the calculated values we can construct a machinability index scale which will show the lowest, highest threshold values and machinable values. Low Mach inability Index Scale High Inferences from the scale 4.605 Least threshold value 7.887 evaluated value/ machinable value 10.631. . It was discovered that the number we arrived at from our evaluated values was 7.887, which was higher than 7.618, indicating that it is machinable. Calculating the permanent and comparing it to the scale we created will allow you to determine the machinability of any material. A future scope regarding this analysis, experimental approaches can be done for the calculation of machinability Index of Laser Beam Machining (LBM).

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