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Multi Criteria selection of Optimal Metal Matrix Composite machining process parameters

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Abstract

Metal matrix composite is a new trend in material science, where recent studies are carried out and still going on for various composite materials. Machining parameters for any material are an important consideration in quality output and process optimisation. Machining of composites with optimised machining parameters is very important to get better resulting quality and optimised use of resources. In this paper, machining input parameters considered speed of spindle, feed rate, weight of SiC and resulting machining parameter such as roughness value of machined workpiece, thrust force, burr height for metal matrix composite dataset is used and analysed using weighted sum method to find out optimised parameter with considering importance factor for output requirement. Individual performance and weighted normalised score (on the basis of importance factor considered for the result to achieve as per requirement) is given to the result dataset and found best optimised parameter data when equally equivalence is required for output result parameters. Multi-Criteria Decision-making weighted sum method is used to find out optimal parameters for optimising its resulting parameters from the dataset.

Keywords: Metal Matrix Composite, Multi-criteria decision-making, weighted sum method, machining parameters,

1. Introduction

Metal Matrix Composites are the composite materials with microstructures involving a continuous metal phase (called matrix) in to which another phase, or the number of phases, have been introduced artificially. This makes a difference between conventional alloys whose having microstructures which developed during naturally occurring phase transformation process[1]. Metal matrix composite is simply defined as a material with having at least two constituents, one should be metal necessarily and the other might be metal or another constituent such as an organic compound or might be ceramic. It gives the freedom to assemble their ideal micro-structure by bypassing its thermodynamic restrictions which generate during solidification and the aging reactions. These reactions limit the range of micro-structures which can be produced by processing conventional metallurgic processes [1]. We can change its physical properties with its micros-structure as requirements. Metal Matrix Composites offer unique balancing in physical and mechanical properties for applications. Metal Matrix Composites also provide better thermal conductivity and also better electrical conductivity, resistance to reactive environment, better impact resistance and erosion resistance, improved fatigue as well as fracture properties. Also, Metal Matrix Composites gives better stiffness and strength than the matrix part of metal matrix composite, it offers better wear resistance and also the low coefficient of thermal expansion, thermal and electrical properties[2]. Metal matrix composite machining process depending factors considered as operational parameters such as mechanics of metal cutting, properties of tool such as material, shape, conditions, geometry, machining environment such as dry, wet, medium quantity lubrication, workpeice properties such as mechanical properties which dependant on material micro-structure and composition, metallurgical properties, workpeice dimensional parameters.[3-5]. It is found by the author that, to understand the machining ability of metal matrix composites factors such as chip formation, machining forces, surface integrity are important [6]. The author reported that, to predict forces for cutting Metal Matrix Composites, mechanics model considers three factors for generation of forces and are chip formation, its breaking condition and particle fracture. In general material removing machining processes like CNC milling factors affecting are cutting speed, feed rate, depth of cut, width of cut [3] and for drilling operation spindle speed, feed rate [7]. As per the studies shows, considering most affecting factors are feed rate, spindle speed and weight of SiC as influential for quality output of machined surface and well utilisation of resources such as tool and machining velocities. It is important to understand the relationship between different parameters which are considered as controllable and to find the needful parameters which affect machining operation's quality. It is needful to optimize material parameters considered in cutting operation so that to obtain an increase in tool life and improved productivity, which is affected by factors like roughness value of machined surface then tool wear, cutting forces as well as feed and thrust force [8]. Optimization is also important for understanding and controlling any process [9-13]. To obtain enhanced quality and productivity, precise control is followed as a pre-requisite. It is also needful for the evaluation of tool wear mechanism related to the operation, tool wear to find tool life [14]. Considering the cutting condition regulates the machining operation with the help of forces developed during cutting, surface finishing of the workpiece for machining operation and the tool life. So, it becomes important to optimize machining parameter [15-17]. Factors considered for affecting on optimization of metal matrix composite's machining operation are spindle speed, thrust force, feed rate, weight of Silicon Carbide, burr height and surface roughness. As discussed in the paper, with an increase of feed rate gives a decrease in shear stress and normal stress[18]. Tool life preferably considered affecting with feed rate and forces developed in the machining process. Feed rate is the linear speed of the tool as it travels along the part contour. It is found that[19], the surface roughness of composites tested with machining parameter results, roughness value for machined surface decreases with an increase in cutting speed while increases with an increase in feed rate. Author stated[20], in drilling operation at low speed and feed rate give result in low tool wear as well better surface quality. Further investigation carried out by the author[21] is that, the feed rate is found mostly influencing factor with cutting speed for resulting surface roughness of composites after machining operations carried out. In another article [22] also this is found feed rate is a major affecting factor for resulting surface finish as well as thrust force developed in the machining process and burr height. We are aware of that; the surface roughness is a parameter used to give the quality of finishing for surfaces. Surface finish is also significantly important as per an aspect of optimizing quality. Thrust force is a major term used in mechanics of machining operations. It influencing for tool wear directly so which affect indirectly on tool life. Silicon carbide is metal matrix composite's other constituent which influences on mechanical properties. In this study, comparative parameters considered as feed rate, speed and weight of SiC because all these parameters directly affect on quality of machining and resulting parameters considered as surface It is found in recent studies that, machined surface's quality is better when surface roughness, thrust force and burr height are minimum.

2. MCDM with Weighted Sum Method

The Multi criterion Decision-Making (MCDM) is significantly taking as a veri similar tool which analyzes complex real type problems because of their intrinsic ability used to judge different options on exploring various criteria for selecting possible of the best or well suit alternative. Probably the weighted sum model (WSM) is the most generally used approach or method for one-dimensional problems. The WSM is considered as the simplest available method, which mostly applies to one-dimensional problems, because the fact is that process follows an intuitive approach. The additive valued postulate is applied, which gives that the overall value of each and every alternative is equivalent to its total sum of the product of responses. In problems with the same ranges of units across criteria are easily weighted sum model is easily applicable [23–25]. Though other methods like TOPSIS [26], PSI [27], Taguchi six-sigma [28] exists, weighted sum method is perhaps the simplest one. Weighted sum model uses the summation of the product of criteria value and equivalence percentage considered for resulting criteria to find the best suitable criteria.

$$A_{WSM\ score} = \max_{x} \sum_{y=1}^{n} a_{xy}.w_y, \quad \text{for} \quad x = 1, 2, 3, ..., m$$

Formulation for WSM is given above if ‘m’ alternatives with ‘n’ criteria then best suitable alternative we can find with the expression shown above, where $A_{WSM\ score}$ for the best suitable criteria, n is number of decision to be selected for criteria, m is numbers of criteria, a_{xy} is actual value of x^{th} alternative for y^{th} criteria.

3. Results & Discussion

From the experimental dataset shown in table 1, with varying parameter feed rate (mm/min), spindle speed (rpm) and weight of SiC (%) content and found the values for roughness value for the machined surface, thrust force and burr height. It is found from the dataset, at spindle speed 1000 rpm, 50 mm/ min feed rate and 5% of the weight of SiC give minimum thrust force of 640 N and at spindle speed 3000 rpm, feed rate 150 mm/min and SiC weight with 15% gives maximum 947 N thrust force. Similarly, for surface roughness maximum value of 6.58 um is found at 1000 rpm of spindle speed, feed rate with 150mm/min and 5% of weight of SiC While, minimum surface roughness of 1.8 um is found at spindle speed of 3000 rpm, feed rate 100 mm/min and 15% weight of SiC. In the case of burr height, we got minimum value 0.147mm at 1000rpm spindle speed, feed rate 50 mm/min and weight of SiC 15%. In the other hand for the maximum value of 0.301mm at 3000rpm spindle speed, 150 mm/min feed rate and 5% of the weight of SiC.

Table 1: Input variables and experimental responses reference and cited from [5]

Exp. no.	Spindle speed (rpm)	Feed rate (mm/min)	Wt of SiC (%)	Thrust force (N)	roughness value for machined surface (um)	Burr height (mm)
1	1000	50	5	640	5.2	0.182
2	1000	50	10	672	4.42	0.164
3	1000	50	15	706	3.76	0.147
4	1000	100	5	736	5.98	0.228
5	1000	100	10	773	3.76	0.205
6	1000	100	15	811	3.19	0.184
7	1000	150	5	858	6.58	0.273
8	1000	150	10	901	5.59	0.246
9	1000	150	15	946	4.75	0.221
10	2000	50	5	642	3.9	0.191
11	2000	50	10	674	3.32	0.172
12	2000	50	15	708	2.82	0.155
13	2000	100	5	739	4.49	0.239
14	2000	100	10	776	2.82	0.215
15	2000	100	15	814	2.4	0.193
16	2000	150	5	861	4.93	0.287
17	2000	150	10	904	4.19	0.258
18	2000	150	15	949	3.56	0.232
19	3000	50	5	641	2.93	0.201
20	3000	50	10	673	2.49	0.181
21	3000	50	15	706	2.11	0.163
22	3000	100	5	737	3.36	0.251

23	3000	100	10	774	2.11	0.226
24	3000	100	15	812	1.8	0.203
25	3000	150	5	859	3.7	0.301
26	3000	150	10	901	3.15	0.271
27	3000	150	15	947	2.67	0.244

From above dataset, it is observed that, when feed rate increases it results in increased surface roughness value, burr height and thrust force increases simultaneously, so to optimise these parameters, we have to use low feed rate. As spindle speed increases an increase in thrust force and burr height but a decrease in surface roughness, so we have to control it together. The weight of SiC influence to metal matrix composites as increases weight of SiC results in an increase in thrust force while a decrease in surface finish and burr height. The parameters shown with performance value in table 2, which is rated from minimum value 1.0000 to decreasing percentage relative to minimum, indicated value with respect to performance under varying criteria for thrust force, burr height and surface roughness. This performance scores 1.0000 shows individual best suitable parameter for optimal output for only that parameter. A weighted normalised score is calculated with consideration of importance factor considered 33.3333% for every single result to be required in overall resulting machined surface. Finally, rank is given as per summation of weighted normalised score found for all three considered output parameters surface roughness, burr height and thrust force. In table 3, shows weighted normalized values for alternatives which are sorted with weighted sum method and given them equal percentage with considering as parameters to be optimised.

Table 2: Performance value, Weighted normalized values and Rank of various alternatives

Exp. No.	Performance value			Weighted normalized values			Rank
	Thrust force (N)	**Surface roughness (um)**	**Burr height (mm)**	**Thrust force (N)**	**Surface roughness (um)**	**Burr height (mm)**	
1	1.00000	0.34615	0.80769	0.33333	0.11538	0.26923	12
2	0.95238	0.40724	0.89634	0.31746	0.13575	0.29878	10
3	0.90652	0.47872	1.00000	0.30217	0.15957	0.33333	5
4	0.86957	0.30100	0.64474	0.28986	0.10033	0.21491	20
5	0.82794	0.47872	0.71707	0.27598	0.15957	0.23902	15
6	0.78915	0.56426	0.79891	0.26305	0.18809	0.26630	13
7	0.74592	0.27356	0.53846	0.24864	0.09119	0.17949	27
8	0.71032	0.32200	0.59756	0.23677	0.10733	0.19919	25
9	0.67653	0.37895	0.66516	0.22551	0.12632	0.22172	22
10	0.99688	0.46154	0.76963	0.33229	0.15385	0.25654	11
11	0.94955	0.54217	0.85465	0.31652	0.18072	0.28488	6
12	0.90395	0.63830	0.94839	0.30132	0.21277	0.31613	3
13	0.86604	0.40089	0.61506	0.28868	0.13363	0.20502	18
14	0.82474	0.63830	0.68372	0.27491	0.21277	0.22791	14
15	0.78624	0.75000	0.76166	0.26208	0.25000	0.25389	9
16	0.74332	0.36511	0.51220	0.24777	0.12170	0.17073	26
17	0.70796	0.42959	0.56977	0.23599	0.14320	0.18992	24
18	0.67439	0.50562	0.63362	0.22480	0.16854	0.21121	21

19	0.99844	0.61433	0.73134	0.33281	0.20478	0.24378	7
20	0.95097	0.72289	0.81215	0.31699	0.24096	0.27072	4
21	0.90652	0.85308	0.90184	0.30217	0.28436	0.30061	1
22	0.86839	0.53571	0.58566	0.28946	0.17857	0.19522	16
23	0.82687	0.85308	0.65044	0.27562	0.28436	0.21681	8
24	0.78818	1.00000	0.72414	0.26273	0.33333	0.24138	2
25	0.74505	0.48649	0.48837	0.24835	0.16216	0.16279	23
26	0.71032	0.57143	0.54244	0.23677	0.19048	0.18081	19
27	0.67582	0.67416	0.60246	0.22527	0.22472	0.20082	17

Fig. 1 shows the performance score as per weighted normalised values for carrying out in experiment number reading shown in table 1. If we change the importance factor for weighted normalised score according to own requirement for output resulting parameter as surface roughness, thrust force and burr height together or as per different combination, it will give different best suitable parameter set from the input dataset as per criteria and alternatives.

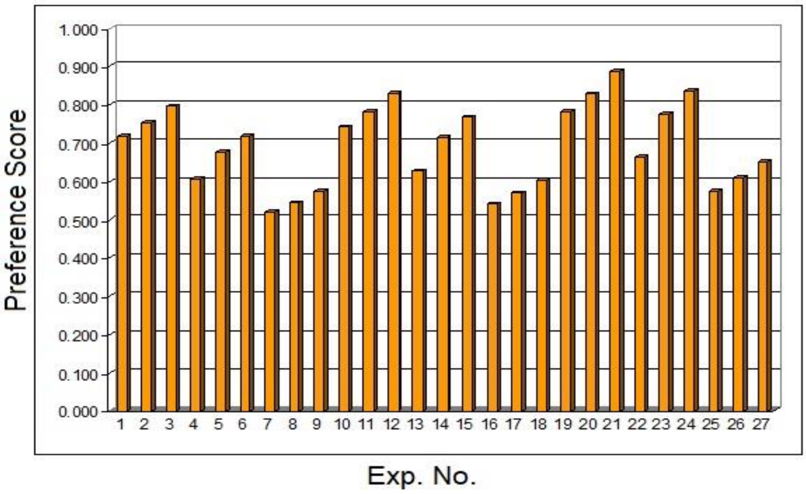

Fig. 1: Preference score of various alternatives

4. Conclusion

It is concluded from the analysed performance score for a dataset of comparative parameters as feed rate, speed, the weight of SiC with output parameters used surface roughness, thrust force and burr height experiment no. 21 will give optimised output parameters with consideration of equal importance for output parameters in resulting machined quality as well as better utilisation of available resources such as tool and work specimen metal matrix composite. Weighted sum method used to select optimal criteria to get better quality, where all resulting parameters surface roughness, thrust force and burr height considered equally optimised output requirement. When performance score is given to resulting parameters, it only shows which one is best individually, but after giving a weighted normalised score with the requirement of equivalence output gives optimal parameter set from the dataset used for optimisation. Concluded parameter set give control over all resulting parameters as per required optimisation with better quality.

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