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Research Article

Parametric Optimization of CGI on Milling Machine

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Abstract

The industrial application of compacted graphite iron in the automotive industry is taking a rather long time due to its uneconomic machinability, because of a significant decrease in tool life. After six years of holistic research of the PTW in cooperation with foundries, manufactures and material scientists, the wear mechanism was understood and clarified: Sulphur in the microstructure of cast iron has direct influence on the formation of a manganese-sulphur layer on the cutting edge. For machining gray cast iron this layer protects the cutting edge against abrasive wear. In case of CGI no layer formation occurs. Against the abrasive wear new cutting materials and tools for the machining of CGI must be developed. Compacted Graphite Iron (CGI) has an important role in manufacturing of new generation engines. Better strength of CGI, as compared to flake graphite iron (FGI), allows CGI engine to perform at higher peak pressure. This can give higher fuel efficiency and lower emission rate. However, the machinability of CGI is poor as compared to FGI. The machinability of CGI is an area that needs to be studied in a better way to cut the production cost of the engine. It is a well-known fact that the as-cast engine block has varying microstructure and mechanical properties due to different cooling rates at different locations of such a geometrically complex component. This has highlighted the need for studying machinability as a function of microstructural and mechanical properties so that the machining process could be optimized.

Keywords: *Parametric Optimization, CGI, Milling Machine*

Introduction

Machining is one of the most important and widely used manufacturing processes in engineering Industries. Today's machining processes are caught between the growing need for quality, high process safety, minimal machining costs, and short machining times.

Compacted Graphite Iron (CGI) is an interesting material that could be used in diesel engine blocks. One reason why engine manufacturers are interested in the material is because of its mechanical properties (higher hardness, tensile strength, etc). CGI has strength of at least 75% greater than gray iron and a roughly twice higher in fatigue strength; hence, less material is required for automobile engine. In addition, it enables thinner wall sections without losing its mechanical strength. The main disadvantage with this material is its poor machinability. Compared with machining gray iron, tool life for milling operations in CGI are half (1).

High productivity is the goal of any company so as to achieve high rate of profit. To get higher production rate, it is then necessary to shorten the machining time or in other words increase MRR (Material Removal Rate). That means that you will need to use higher insert densities and higher feed rates to achieve the desired MRR's for CGI. The correlation between tool life with MRR is also thoroughly studied during the period of this project.

In order to achieve high production rate and higher tool life, optimal cutting parameters have to be chosen. The objectives are to maximize both tool life and MRR. Full factorial experiments are performed during machining of CGI. The experiment results are then analyzed using MINITAB software. Optimization technique is used to find out the optimal parameters that fulfill both objectives. At last, the optimum machining parameters are pointed out and recommended.

Literature Review

F. Mocellin, E. Melleras *et. al.* and W. L. Guesser studied that CGI – Compacted Graphite Iron – has reached an important status for automotive industry, mainly in the last ten years. The material has been used for manufacturing parts as brake discs, exhaust manifolds, engine heads and diesel engine blocks. The superior strength characteristics of CGI, as compared to gray iron, allows the manufacturing of engines for higher pressure operating combustion chambers, therefore more efficient and with lower emissions levels. Also thinner walls are possible, generating lighter engines.

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However there are some technical challenges to overcome, mainly related to the machining process of the parts. This research intends to study the machinability of CGI, in order to develop a new alloy with improved characteristics of machinability, so the production costs for CGI automotive parts can be reduced.

S. Dawson *et al* T. Schroeder concludes that Compacted Graphite Iron has entered the realm of high volume series production. While conventional materials have begun to reach durability limits in many applications, CGI provides a new opportunity to satisfy the performance and package size requirements of the next generation of engineered components, particularly in applications with simultaneous thermal and mechanical loading such as cylinder blocks and heads. The successful references provided by the first high volume production engines for Model Year 2004 vehicles will provide the confidence needed for further production commitments and the expansion of CGI to a variety of applications.

N. Naresh, K. Rajasekhar, P. Vijaya Bhaskara Reddy experimentally investigated Milling composite materials is a difficult task due to its heterogeneity and the number of problems, such as surface delamination, fibre pullout associated with the characteristics of the material and the cutting parameters that appear during the machining process. Glass Fibre Reinforced Plastics (GFRP) composite is considered to be an economic alternative to heavy exotic materials. It is widely used in different fields such as aerospace, oil, automotive and aircraft industries due to their light weight, high modulus, specific strength and high fracture toughness. In this work, a plan of experiment based on Taguchi's L27 orthogonal array was established and milling experiments were conducted with prefixed cutting parameters for GFRP composite plates using solid carbide end mills.

Gustav Grenmyr, Anders Berglund, Jacek Kaminski, Cornel Mihai Nicolescu analysed the tool wear could on the basis of their wear appearance be classified in three different wear categories; A, B and C. In the wear category A, abrasive wear, adhesive wear and delamination wear could be seen. In the wear category B, the predominant wear mechanism was chipping. The wear appearance in wear category C indicated attrition wear and dissolution via diffusion. Classification of the wear mechanismsgave knowledge that could be used in tool design. The results showed that increasing nodularity has impact on wear at moderate and high cutting speed but not at lower cutting speed. Machining of all materials at high cutting speed, 400 m/min, led to complete degradation of the edge line. A small difference in nodularity from 5 % to 20 % has more significant impact on wear than from 20 % to 62 %. This seemed to be correlated with the difference in ultimate tensile strength between the materials.

Experimentation Set Up

The face milling tests were conducted on vertical machining using Sandvik Carbde milling inserts on CGI block material with dimensions of 400 x200 x 100 mm. The cutting speed ranges from 120-250 m/min. The feed rate was selected to be 5-15 mm/min. While a constant depth of the cut was chosen as 3 mm for entire experiment. It is important to note that the values for these cutting conditions were selected with respect to the tool insert manufacturer's (Sandvik) and Volvo and Scania recommendations. Therefore, the variable parameters are going to be feed per tooth (fz) and cutting speed (Vc).

Composition of GCI

Elements	C	Si	Mn	S	P
CGI	3.1	2.5	0.50	0.15 Max	0.09 Max

Figure Milling Machine

Design of Experiment (DoE)

Designed experiments were carried out for a selected combination of cutting speeds and feeds. The most preferred method of experimentation is full factorial experiments where experiments are carried out for all combinations of variables. In cases where many variables are involved, full factorial experimentation is not feasible because of the time constraints and the cost involved in performing these experiments. The most efficient way of carrying out experiments is by using the Design of Experiments (DoE) method. With the full factorial designs, in each complete trial or replication of the experiment all possible combinations of levels of the factors are investigated. Generation of DoE is created according to the procedures from *State-ease of Design-expert 8*. A full factorial of two factors and three levels are utilized for the experiments. A three level provides an insight if it is linear or not.

Controlled parameters	Levels			Units	Observed Values
	L_1	L_2	L_3		
Cutting speed	150	200	250	m/min	1. Material Removal Rate (mm^3/min)
Feed rate	5	10	15	mm/min	
Depth of cut	2	4	6	mm	

Milling tools and inserts

Proper selection of tools and inserts is critical for achieving maximum productivity during machining of CGI. The choice of tool material and cutting geometry are crucial. Nevertheless, no matter how right selection of the tool is, if the machining conditions are not up to standard, especially the cutting data and general stability of the machine, hence optimum productivity might not achieved. Vibrations and lack of rigidity in tool holder and clamping can also enhance the tool wear and hence effects on reaching a higher productivity.

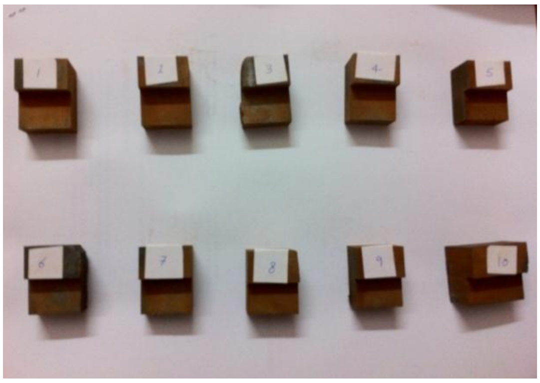

Figure-CGI Material after and before machining.

Results

In order to meet high production rate and stable process, machining parameters have to be chosen in the best possible way. For such optimization, it is necessary to represent the machining process in a model. Accuracy and possibility of determining global optimum solutions depend on the type of modeling technique used to express the objective functions and constraints in terms of the decision variables. Accurate and reliable models of a machining process can compensate for the inability to completely understand and adequately describe the process mechanism. Thus, formulation of an optimization model is the most important task in the optimization process.

Design of Experiment

As per the Taguchi quality design concept L9 orthogonal array table.

1. Three control factors were chosen each at 3 levels

a) Cutting speed (m/min)
b) Feed rate (mm/min)
c) Depth of cut (mm)

2. Three response parameters will measure:-
a) MRR(mm^3/min) (Metal removal rate)

The experimental layout for the machining parameters using the L9 orthogonal array was used in this study. This array consists of three control parameters and three level, as shown in table 4.1 In the Taguchi method, most all of the observed values are calculated based on ‘the Larger the better’. Thus in this study the observed values of MRR.

Taguchi’s L9 orthogonal array with values of levels

Experiment No.	Cutting Speed	Feed rate	Depth of cut
1	150	5	2
2	150	5	4
3	150	5	6
4	200	10	2
5	200	10	4
6	200	10	6
7	250	15	2
8	250	15	4
9	250	15	6

The L9 Orthogonal array with Performance

Experiment No.	Cutting Speed	Feed rate	Depth of cut	MRR
1	150	5	2	4.32
2	150	5	4	5.25
3	150	5	6	6.40
4	200	10	2	7.45
5	200	10	4	6.95
6	200	10	6	7.15
7	250	15	2	7.15
8	250	15	4	4.92
9	250	15	6	7.50

Analysis of variance (ANOVA) for S/N Ratio w.r.t MRR

Source	Cutting Speed	Feed Rate	Depth of cut	Error	Total
DF	2	2	2	2	8
Seq SS	5.3352	2.5802	3.4998	0.135	11.5504
Adj SS	5.3352	2.5802	3.4998	0.135	
Adj MS	2.6676	1.2901	1.7499	0.068	
F	39.46	19.08	25.89		
P	0.025	0.05	0.037		
%Contribution	46.19	22.34	30.3	1.17	

The tables include ranks based on delta statistics, which compares the relative magnitude of effects. The delta statistic is the highest average minus the lowest average for each factor. Minitab assigns ranks based on delta values in descending order; the highest delta value has rank. 1 and rank 2 is assigned to the second highest, and so on. The ranks indicate the relative importance of each factor to the response.

Response Table for Signal to Noise Ratio Larger is better

Level	Cutting Speed	Feed Rate	Depth of cut
1	14.41	15.75	14.55
2	17.12	15.03	16.45
3	16.14	16.90	16.68
Delta	2.71	1.88	2.14
Rank	1	3	2

The S/N response graph for Material Removal rate is shown in Fig 4.1. The greater average S/N ratio corresponds to the max MRR. From the S/N response graph Fig 4.1, it is concluded that the optimum parametric combination is Cutting Speed (200), Feed Rate (15), and Depth of Cut (6). In other words, it is this combination of parameters that gives the max MRR for the machined material.

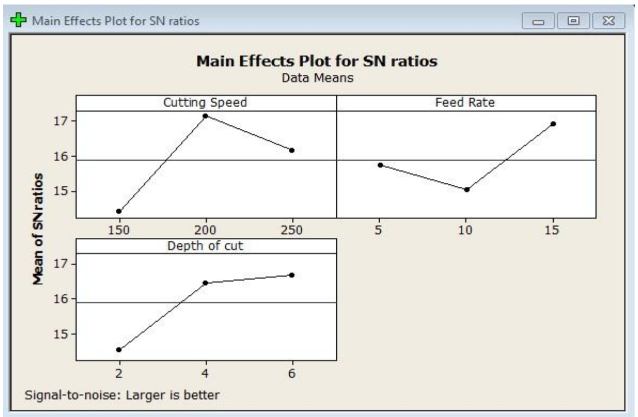

Figure- S/N Ratio for MRR

Conclusion

From the experimental results, S/N ratio and ANOVA analysis and predicted optimum machining parameters, the following conclusions are drawn:

1. From ANOVA table and Response table for Signal to Noise, based on the ranking it shows that Cutting Speed has a greater influence on the MRR followed by Depth of cut and Feed rate had the least influence on MRR.
2. The optional setting of process parameters for maximum material removal rate is Cutting Speed (200), Feed rate (15) and Depth of Cut (6).
3. The validation experiment confirmed that the error was less than 0.1352 % between equation and actual value.

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