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ECONOMIC ANALYSIS OF GRINDING WHEEL: A CASE STUDY

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ABSTRACT

Grinding is an abrasive machining process which uses a grinding wheel as the cutting tool. The performance of the grinding wheel depends upon the type of abrasive material, grit size, wheel grade, wheel structure and bonding material. The quality of the machined component depends on the selection of above parameters. In the grinding of camshaft journals, due to the continuous use of grinding wheel different type of problem occurs; one of the problems is frequent dressing which affects production rate. To overcome this problem, Technique for Order of Performance by Similarity to Ideal Solution (TOPSIS) method is used to select the suitable abrasive material on the basis of four criteria like hardness, toughness, crystal size and wheel cost. The observed result is verified by the bivariate diagram between two conflicted criteria, i.e. hardness and toughness of abrasive. After that, the production rate and grinding cost per part are calculated. The results show that the Seeded-Gel (SG) alumina oxide abrasive gives the better grinding performance and not requires dressing frequently.

KEYWORDS: *Grinding Wheel, TOPSIS method, Seeded-Gel abrasive, Total Variable Cost.*

1. INTRODUCTION

The industries achieve higher productivity to sustain in the market, even increase their market share in the global world. It is becoming more important for the machined components industries due to the high growth of the manufacturing sector in the world, for that is essential to optimize the process. The optimum process obtains where the desired quality of the product, the maximum possible production rate with minimum cost per part.

In the manufacturing of machined components, better surface finish and dimensional accuracy can be achieved by the use of the abrasive machining processes. The one is the grinding process, usually one of the last steps towards value addition of product or in the sequence of machining operations. Grinding is an abrasive machining process that uses a grinding wheel as the cutting tool. The wheel contains mainly two elements, i.e. abrasives and bonding materials.

The objectives of this study to improve the performance of the grinding wheel, reduce the frequency of dressing, minimize grinding cost, and increase the production rate. For achieving to all these objectives need to use the efficient grinding wheel. The performance of the grinding wheel depends upon its elements, *i*.e. abrasive material, grit size, wheel grade, wheel structure and bonding material. The abrasives act as a cutting tool and the bonding material as a tool holder. Thus, the abrasive is the primary driver of the grinding wheel which directly influences the performance of the process because it interacts with work material.

Therefore, choose the abrasive material for grinding wheel depending upon the criteria or their properties are hardness, fracture toughness, crystal size and cost of the wheel with vitrified bonded of finer grit size (80-100) and structure of point 8 of the standard scale. These criteria highly affect the performance of grinding wheel which is described in detail in the next section of this paper.

Grinding wheel technology grows very rapidly in the recent decades from low speeds conventional grinding wheels which employed in the early 20th century to advanced conventional abrasive and superabrasive grinding wheels that operate at high speed. Now a day, various types of abrasive material available in the market, but all of abrasive do not meet to the requirement for a specific grinding operation. Consider four alternative abrasive materials of alumina oxide with the different chemical composition are regular or grey alumina oxide, pure white alumina oxide, ruby alumina oxide and seeded gel abrasive particles which are adaptable in the present working condition.

The suitable abrasive material of grinding wheel, select on the basis of their properties or various criteria which are conflicting with each other. It is a very tedious task for the decision maker to select the suitable abrasive material of grinding wheel. Therefore, the abrasive selection problem is solved by the use of multi-criteria decision-making methods. Here, TOPSIS method is used to rank the various types of wheel abrasives and select the suitable abrasive material for efficient grinding. The observed result by TOPSIS is confirmed by plotting the bivariate diagram between two conflicting criteria for optimality, calculate production rate and economic analysis on the basis of laboratory tested data and compare it with the existing wheel results.

Lindsay [3] tested SG abrasives in the laboratory to learn their operating characteristics in different conditions and evaluated the performance in terms of G-ratio, the surface finish of work material, material removal rate, tangential force, the power required to grind and compared with conventional abrasive products (white and dark alumina oxide). They are found that the SG abrasives wear at a very low rate and have a longer wheel life, increases material removal rate and also maintained surface finish and geometry for many parts; it will act better when the small depth of dress is used. Jusko, Ondrej [1] was found that the Seeded-Gel abrasive grains are the most suitable for grinding hardened bearing steel in order to obtain the best surface roughness and geometrical accuracy. Milak, P.C. et al [7] studied the influence of the microstructure on erosive wear resistance of alumina based ceramic material. It was found that the erosive wear of alumina mostly influenced by the alumina grain size and grain refinement process. Roszkowska [8] described the TOPSIS technique of multi-criteria decision-making method for crisp and interval data and also presented an algorithm for single and group decision maker. Tripathi [11] et al developed empirical models for surface roughness and material removal rate on AISI D2 steel by using Response Surface Methodology and found the effect of input parameters as wheel grade, grit size and depth of cut. Chekole and Deshpande [12] reviewed the past literature relevant to the cylindrical grinding process for different materials which describe the effect of various process parameters. It was found the gaps in the literature as the researcher has taken limited input parameters which gives an incorrect conclusion and not worked for En45 steel material. Maity and Chakraborty [13] worked for the selection of grinding wheel abrasive material based on the desired mechanical and physical properties of abrasive by decision-making approach i.e. fuzzy TOPSIS method for enhanced grinding performance.

It is evidently observed from the literature survey that the past researchers work for optimizing the process parameters and select suitable abrasive materials of grinding wheel by the use of various techniques or experimental studies. But, there is a lack of a comprehensive. So, need to a methodology which deals with the grinding wheel abrasive material selection problem. This paper applies decision-making technique of order performance by similarity to ideal solution (TOPSIS) method for grinding wheel abrasive material selection while considering those alternatives which are adaptable in the existing working environment and also done an economic analysis of the selected grinding wheel abrasive material. It gives satisfactory results for a particular grinding application which are economically beneficial and not require major changes in the existing system.

The work in this paper is divided into two stages. 1) Selection of suitable abrasive by decision making technique 2) Verification of the observed result by analytical, empirical relations on the basis of past researches and laboratory data and compare it with the performance of the existing wheel.

2. PROBLEM FORMULATION & OBJECTIVES

In the grinding of camshaft journals, the grinding wheel requires frequent dressing which affects the production rate and manufacturing cost.

Thus, the objective of this study is to overcome the above problems and recommend the suitable abrasive material which improves the performance of the grinding wheel and productivity of the firm.

3. METHODOLOGY

The goals of this study are achieved by the following steps which are described as:

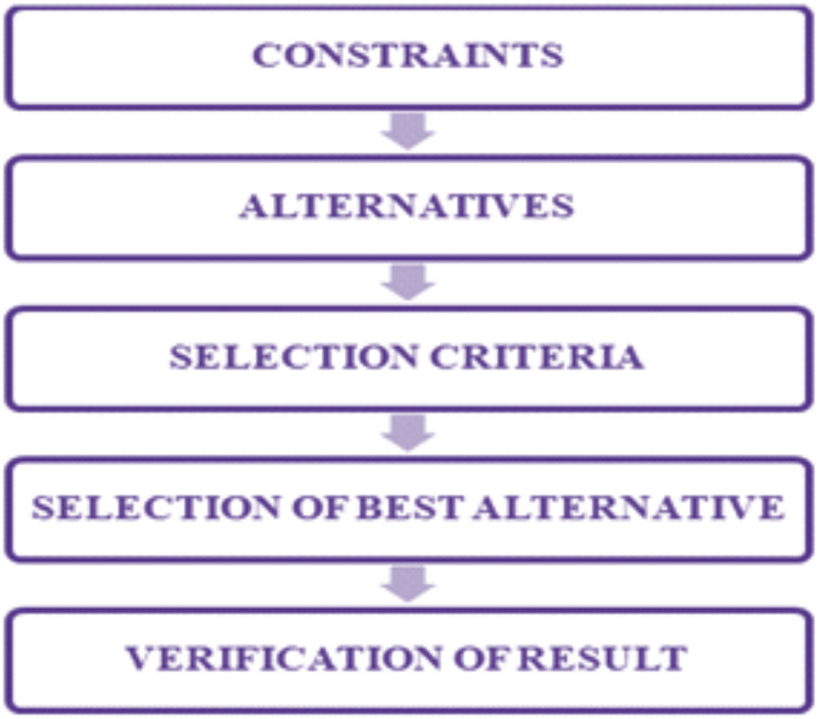

Figure 1. Steps to achieve the goal of this study

3.1. Constraints

The constraints exist in the manufacturing system which can't change or replace in the way of selection of alternative abrasive material for grinding wheel. The following are described as:

3.1.1. Work Material

The material used for camshafts is En45 steel which is induction hardened to obtain hardness in the range of 58 – 63 HRC.

3.1.2. Required Surface Finish & Dimensional Accuracy

The surface roughness of bearing journals require less than 0.5 Ra value and dimensional tolerance limit is 10 µm in all dimensions.

3.1.3. Grinding Machine & Speed

The cylindrical grinding machine of model CGM 300-650 is used in the firm. It is low-speed conventional grinding machines which are run at 1200-1800 RPM.

3.1.4. Wheel Size & Shape

The industry used 500*40*203.3 size of the grinding wheel of a straight shape.

3.1.5. Dressing Conditions

The existing conventional grinding wheels are dressed by single or multipoint diamond dresser.

3.1.6. Grinding Fluid

In the camshaft bearing journals grinding 5% concentrate water-soluble synthetic oil used for alumina wheels.

3.2. Alternatives

The alternative abrasive material of grinding wheels which are suitable or satisfied to the requirements of the working conditions. The following types of abrasive material are listed below:

3.2.1. Regular or Grey alumina oxide

This is fused alumina oxide abrasive which is less pure and contains approximate 3% TiO_2. When increases titanium percentage than increase toughness, but reduce hardness. It has lower hardness and friability, and higher toughness as compared to white alumina due to which is more durable. It is also called brown alumina oxide. It's normally used in medium to high pressure grinding where required semi-finishing, relatively heat sensitive operation on medium to soft materials.

3.2.2. White alumina oxide

These are the purest fused alumina oxide abrasive. It has high hardness, more friable, not durable, and also has sharp fracture facets which provide fast and cool cutting action. They are used in precision grinding of hard ferrous material or high speed steel, high heat sensitive operation.

3.2.3. Ruby alumina oxide

It is produced by adding chromium oxide up to 3% in alumina oxide. It may enhance abrasive material's hardness, also increases toughness by adding a small amount of other additives like TiO_2 or other metal oxides. These abrasive grains are harder and tougher than white alumina oxide abrasive, sharp-edged and blocky. It is used in extremely cool, low stress grinding with low wear of abrasive and free cutting action. It is mostly used in tool room grinding and on abrasive resistant materials.

3.2.4. Seeded-Gel alumina oxide

It is the recent development in the technology of abrasive synthesis. This is not made by fusing or sintering, but instead by chemical precipitation or colloidal dispersion of hydrosol. It has a polycrystalline structure which enables to micro-fracturing of abrasive grains and generates new cutting edges during the grinding process or self-sharpen characteristics. This alumina abrasive grain contains 1000 of microcrystals because of less than 1 µm in size. It is the purest form of alumina oxides and harder (because it's not crushed after sintering) than all fused alumina oxide abrasives. These abrasives are also unusually tough, but self-sharpening because fracture now occurs at the micron level, friable and durable. These are costly due to its manufacturing process, but when it blended with more friable alumina oxide abrasive in the making of wheel than the wheel life increases up to 3 to 5 times. It mostly uses for difficult-to-grind materials in which tight tolerances and no metallurgical damage are specified.

3.3. Selection Criteria

The efficiency of abrasive particle or their performance in the grinding process depends upon the properties of abrasive particles. Here consider the following criteria which highly influence the grinding performance are as:

3.3.1. Hardness of abrasive

It is the most important property of abrasive. The common rule about the hardness is that it should be more than the hardness of work material. It plays an important role in attritious wear (dullness or flattening of abrasive) because the hardness is retained at high temperature and does not occur chemical reaction between abrasive, work material and binder etc. except diamond with ferrous material. The diamond is hardest and softest is zirconia compounded abrasives.

3.3.2. Fracture toughness of abrasive

Another important property is toughness or dynamic strength of abrasive. If the wheel is not tough, abrasive grain fracture rapidly and more wheel wear. It describes the ability of a material to resist the crack propagation and fracture. If the abrasive has higher toughness than less likely to fracture or fragment during the grinding. On the other hand, less tough or more friable abrasive that fracture and generates new sharp cutting points or give self sharpen characteristic. Thus, the medium tougher abrasive required for efficient grinding about 3.5 $MPa.m^{1/2}$.

3.3.3. Crystals size of abrasive

Abrasives are crystalline in nature and it affected by the additive elements, preparation or manufacturing process of abrasive. An abrasive particle contains several crystals which fused together. It is the basic property that affects the various mechanical properties such as hardness, fracture toughness and friability. It is highly influence wheel wear characteristics or performance of grinding.

3.3.4. Wheel cost

When selecting a suitable abrasive material, its cost is also an important criterion whose minimum value is always desired. In the cost of grinding wheel include the cost of abrasive, cost of bonding material and manufacturing cost of the wheel. When considering the cost of grinding wheel, is highly varied with the cost of abrasive used for made in grinding wheels. The cost of abrasive material depends upon their manufacturing processes and their availability. Here, consider the cost of grinding wheels which made of different type of abrasive particles and the most common used vitrified bond of different composition or additive bonding material.

3.4. Selection of best Alternative

It is quite difficult to recommend the best abrasive material for a grinding wheel with considering the number of criteria which are conflicted nature. It considers the problem of MCDM which is solved by the use of TOPSIS method. The quantitative data required for decision matrix in TOPSIS method are shown in table 1. The TOPSIS method procedure for single decision maker shows in the following steps [8]:

Table 1. Quantitative data of different alternatives of abrasive materials [2].

Alternatives	Criteria			
	Hardness (GPa)	Fracture Toughness ($MPa.m^{1/2}$)	Crystal size (µm)	Wheel cost (Rs)
Grey Al_2O_3	17.1	2.5	50	8000
White Al_2O_3	19.4	2.2	50	9500
Ruby Al_2O_3	18.9	2.8	50	12000
Seeded-Gel Al_2O_3	21.5	3.7	1	23000

Step 1. Construct decision matrix by using the above quantitative data and the Weights for attributes or importance to the criteria of the selection are decided by various methods but here give the equal importance to all the criteria. Thus in this way, the weights are normalized to sum one (i.e. The four equal parts of one). Therefore the weighted value (w_j) for each criterion is 0.25.

Let, X is a decision matrix of m alternative and n criteria as:

$$X = (x_{ij})_{m\times n} \quad (1)$$

Step 2. Calculate the normalized matrix because various criteria measured in various units. The values of decision matrix are normalized by various standard formulas. The method used for calculating the normalize value n_{ij} are followed:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (2)$$

For i = 1,..., m; j = 1,…, n.

Step 3. Calculate weighted normalized value as follows:

$$v_{ij} = w_j \cdot n_{ij} \quad (3)$$

For i = 1,…, m; j = 1,…, n.

Where, w_j is the weight of the j-th criterion, $\sum_{j=1}^{n} w_j = 1$

Step 4. Identify positive ideal solution and negative ideal solution. Positive ideal solution A+ has the form:

$$A^+ = (v_1^+, v_2^+, ..., v_n^+) = \{(\max v_{ij} \mid j \in I), (\min v_{ij} \mid j \in J)\}$$

Negative ideal solution A− has the form:

$$A^+ = (v_1^+, v_2^+, ..., v_n^+) = \{(\min v_{ij} \mid j \in I), (\max v_{ij} \mid j \in J)\} \quad (5)$$

where I is associated with benefit criteria and J with the cost criteria,

I = 1,…, m; j = 1,… , n.

Step 5. Calculate the separation of each alternative from positive ideal solution and negative ideal solution respectively. We used traditional n-dimensional Euclidean metric.

$$d_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2}, I= 1,2,…,m. \quad (6)$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}, I =1,2,…,m. \quad (7)$$

Step 6. Determine the relative closeness to the ideal solution.

$$R_i = \frac{d_i^-}{d_i^- + d_i^+} \quad (8)$$

where $0 \le Ri \le 1$, i = 1,2, … , m.

Step 7. Finally ranked the alternatives in the descending order of the value of Ri.

3.5. Verification of Result

The result is confirmed by the use of analytical techniques, empirical relations and compared the observed result with the existing grinding wheel. The necessary data are assumed or taken from the past research or laboratory test reports. The following terms are considered as:

3.5.1. Bivariate diagram between hardness and Fracture toughness

The optimality test condition for the two conflicted terms are defined as that has both properties highest as compared to another and when plotted the graph between them than the point which shows the optimal result is located furthest from the origin or have a longest from the origin. It is shown in figure 3.

3.5.2. Production rate

The production rate is the number of jobs that can be produced within a given period of time. The production rate is the inverse of the total cycle time for a single workstation. In the grinding, total cycle time included basic cycle time (t_t) and total dressing time (t_d). The total cycle time is determined by the equation given below [9]:

$$t = t_t + {t_d}/{N_d} \quad (9)$$

Where N_d is parts produced in one redress period.

3.5.3. Economic Analysis

When the choice of abrasive verifies on the economic aspect, the aim is to determine the manufacturing cost per part. In the comparison of grinding wheel performance, fixed cost remains constant and total variable cost for each wheel is different because it depends upon various variable parameters. So, consider the only total variable cost which plays a vital role in the grinding operation. The total variable cost includes wheel cost, labour cost, machine cost, dressing cost, but the dressing cost is negligible as compared to others in that case and it's not considered for calculation. The various costs are calculated by the use of following equations [9].

The wheel cost C_s as:

$C_s = c_s / N_w$(10)

Where c_s is the wheel cost and N_w total parts produced by the wheel in a whole life.

The Labour cost C_l as:

$C_l = c_l .t$(11)

Where c_l is labour rate and t total cycle time.

The machine cost C_m as:

$C_m = C_{mc} .t / y_t$(12)

Where C_{mc} is the cost of the machine, t times the total cycle time and y_t the payback time.

The total variable cost is given as:

$C = C_s + C_l + C_m$ (13)

4. RESULTS & DISCUSSIONS

The closeness coefficient (R_i) value or ranking order of different grinding wheel is found as shown in the below figure 2:

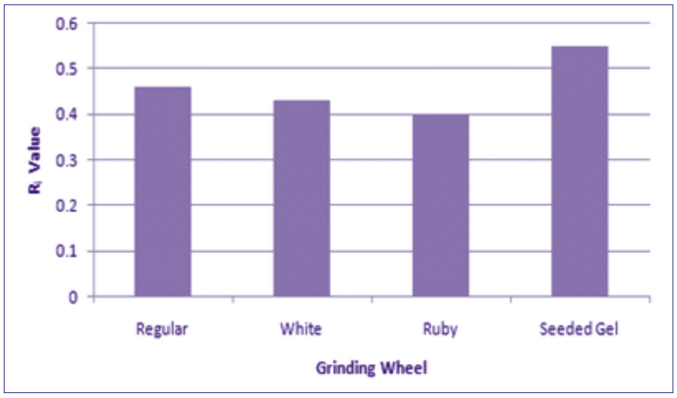

Figure 2. Ranking order of alternatives

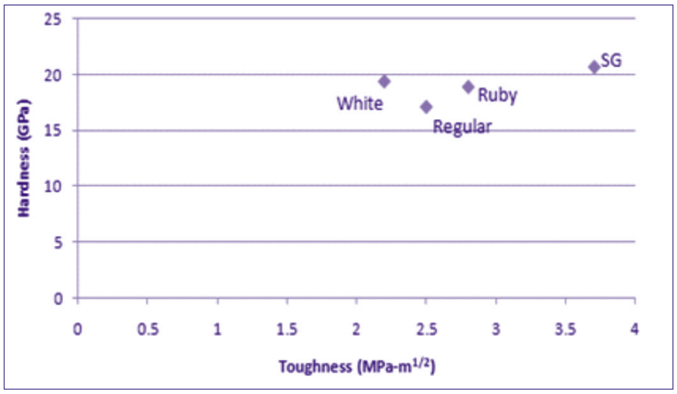

Figure 3. Bivariate diagram between hardness and fracture toughness

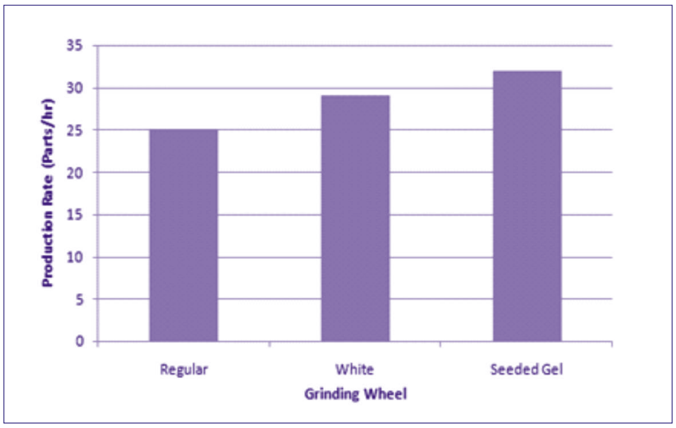

Figure 4. Production rate by different grinding wheels

The SG wheel produces more jobs per hour because it required less number of dressings due to its sharpness or micro-crystal size abrasive. The production rate of different grinding wheels is shown in the figure 4.

The total variable cost per part is lower for SG abrasive wheel is 8.21 Rs/part which is less as compared to presently used white wheel total cost 11.98 Rs/part and grey wheel total cost 10.76 Rs/part. The grinding wheel cost/part of the SG abrasive wheel is low, then grey and last White abrasive wheel. But the machine cost and labour cost is more when used grey abrasive wheel and less with SG wheel and medium form white alumina abrasive wheel. The figures are given below which describe the total variable cost and individual (i.e. Wheel cost, labour cost and machine cost) cost for all three types of grinding wheels.

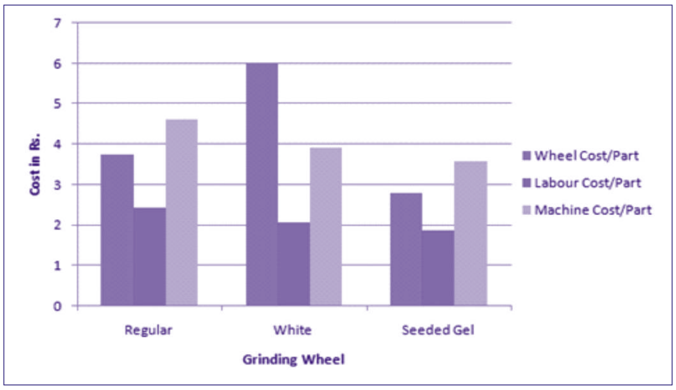

Figure 5. Various types of cost comparison for grinding wheels

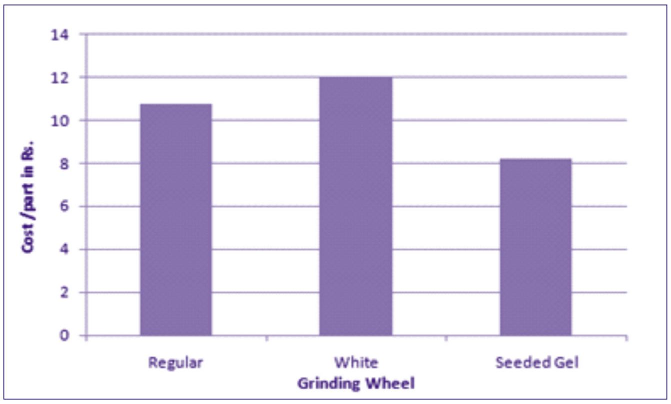

Figure 6. Total variable cost for grinding wheels

When you plot the graph between the total variable cost and production rate for all three types of grinding wheel materials than found that the SG abrasive wheel gives the optimum result as it gives the higher production rate with minimum total cost per part. The figure shows below:

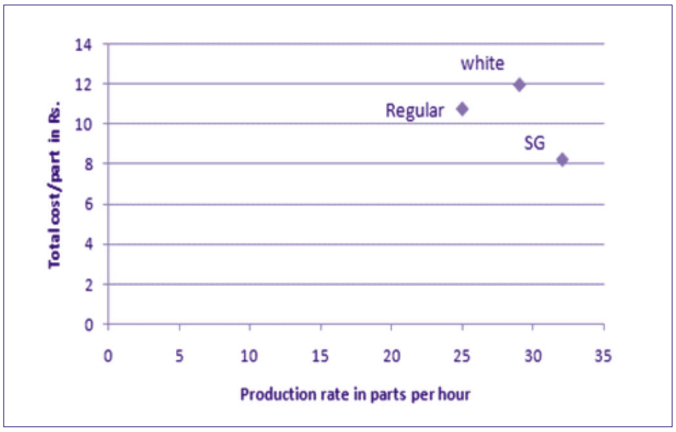

Figure 7. Total variable cost Vs Production rate

5. CONCLUSION

The TOPSIS method deals with both maximize (hardness and fracture toughness) and minimizes (crystal size and wheel cost) criteria to obtain the ranking of listed abrasive material as the first is SG abrasive then grey, white and ruby alumina oxide respectively. The observed result is concluded as follows:

i. The SG abrasive grinding wheel requires less dressing and low wheel wear due to microfracture during the grinding process.

ii. The production rate increases up to 30% as compared to present and less fatigue to the operator (when grinding operation performed on the manual or semi-automatic CGM machine).

iii. The economic aspect, reduce 25% grinding cost per part by the use of the SG alumina abrasive wheel as compared to the existing uses grey alumina abrasive wheel.

Thus, you obtain higher production rate with the minimum cost/part of grinding with appropriate quality by the use of SG abrasive material in the grinding wheel for the grinding of camshaft bearing journals.

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REFERENCES

1. *Jusko, Ondrej (2012), "New Abrasive Material and Their Influence on the Surface Quality of Bearing Steel After Grinding" ActaPolytechnica Vol. 52 No. 4/2012.*
2. *Krell, Andreas et al (1996), "Advances in the Grinding Efficiency of Sintered Alumina Abrasives" Journal of the American Ceramic Society, Vol.79, No.3, 763-769 (1996).*
3. *Lindsay, P. Richard (1989), "The Performance of Seeded Gel Abrasives in the Laboratory and at Customer Test Sites" Aircraft Engineering and Aerospace Technology, Vol. 61 Issue 10, 1989, pp. 20 – 26.*
4. *Maity, SaikatRanjan et al (2013), "Grinding Wheel Abrasive Material Selection Using Fuzzy TOPSIS Method" Materials and Manufacturing Processes, 28: 408–417, 2013.*
5. *Malkin, Stephen and Guo, Changsheng (2008), "Grinding technology: theory and application of machining with abrasives" Industrial Press, Inc., New York, 2nd edition.*
6. *Marinescu, D. Ioan et al (2007), "Handbook of Machining with Grinding wheels" CRC Press, PP185-194.*
7. *P.C. Milak, et al (2015), "Wear performance of alumina-based ceramics-a review of the influence of microstructure on erosive wear" Ceramica 61, 88-103, 2015.*
8. *Roszkowska, Ewa (2011), "Multi-Criteria Decision Making Models by Applying the TOPSIS Method to Crisp and Interval Data", University of Economics in Katowice, MCDM' 11, pp. 200-230.*
9. *Rowe, W. Brian (2014), "principle of Modern Grinding Technology" Elsevier Inc., second edition, PP160-174.*
10. *SeropeKalpakjian&R. Steven,Schmid (2009), "Manufacturing Process for Engineering Materials" Pearson Education India; 5th edition 2009, PP 719-732.*
11. *Tripathi, Deepak et al (2017), "Optimization of Surface Grinding Parameterson AISI D2 Steel Using Response Surface Methodology" Industrial Engineering Journal, Vol. X & Issue No. 6 June – 2017.*

12. *Chekole, Nesredin and Deshpande, Vivek (2018), "Review Analysis on Optimization of Cylindrical Grinding Process Parameters by Using Taguchi Technique" Industrial Engineering Journal, Vol. XI & Issue No. 5 May – 2018.*
13. *Maity, SaikatRanjanand Chakraborty, Shankar (2013), "Grinding Wheel Abrasive Material Selection Using Fuzzy TOPSIS Method" Materials and Manufacturing Processes, 28: 408–417, 2013.*

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