THAI NGUYEN UNIVERSITY

THAI NGUYEN UNIVERSITY OF TECHNOLOGY

LUU ANH TUNG

RESEARCH TO IMPROVE THE EFFICIENCY OF FINAL SURFACE GRINDING PROCESS

Specialty: Mechanical Engineering

Code: 9 52 01 03

SUMMARY OF DOCTORAL THESIS IN ENGINEERING

THAI NGUYEN – 2020

The thesis completed at Thai Nguyen University of Technology

Scientific supervisor: 1. Assos. Prof. Dr. Vu Ngoc Pi

2. Prof. Dr.-Ing. Habil. Banh Tien Long

Reviewer 1:………………………………………

Reviewer 2:………………………………………

Reviewer 3:………………………………………

The dissertation is defended at thesis review board in Thai Nguyen University of Technology

At: xxxhyy'- ……/2020

The dissertation can be found at:

Library of Thai Nguyen University of Technology

Learning Resource Center – Thai Nguyen University

National library of Viet Nam

Introduction

1. Motivation

Grinding has been used in mechanical manufacturing since the 19^{th} century. Around the middle of the 20^{th} century, it was realized that grinding was a strategic machining and a key task for achieving precision and surface roughness. Grinding can process with a very small depth of cut, from 0.05 ÷ 0.09mm; high cutting speed, 20 ÷ 40 m/s with conventional grinding and up to 200 m/s with high-speed grinding. High precision of grinding parts with precision levels of 5 ÷ 7 and low surface roughness after grinding, can reach from 0.2 ÷ 3.2 µm or lower. Because of the above advantages, grinding is the most common finishing and semi-finishing process in mechanical processing, especially the parts that require high precision and low surface roughness. Grinding is especially dominant when finishing fine parts with high hardness, high strength, usually after finishing, etc. It has been reported that grinding operations account for 20 ÷ 25% of the total costs for general machining [14, 64]. Thanks to the technical advances achieved in the field of cutting tool materials, many surface grinding operations have now been replaced by hard milling operations, resulting in a much higher productivity and economic efficiency. However, surface grinding is still an irreplaceable task when final finishing of sheet, thin disk (such as air compressor valve blades, clutch leaves, disc brakes, etc.) or cutting tools. Physical-chemical processes occurring in the grinding area are very complex and make it difficult to control the grinding process to achieve the desired economic and technical efficiency. Therefore, grinding methods are still interested in domestic and foreign scientists.

With grinding, cutting speed (grinding wheel speed $V_đ$) is an important parameter determining the productivity, cost and profit of the grinding job in particular and the processing process in general. When grinding, the cutting speed $V_đ$ is proportional to the diameter of the grinding wheel Ds and the number of rotation of the spindle $n_đ$. Thus, with the same diameter of grinding wheel, the greater the cutting speed if the number of rotation of the spindle is higher. With the grinding machine with constant number of rotation of the spindle when new grinding wheel, the diameter of the stone is large so the cutting speed is high, so the grinding productivity is high. Assuming that with the same grinding wheel, the cost of grinding wheel/h will be high if the life of the grinding wheel is small, for example, the price of a grinding wheel is 360,000 VND / piece, the grinding wheel life is 18h, the cost of grinding wheel/h will be is 20,000 VND/h. In contrast, the cost of grinding wheel/h will be very small if the life of the grinding wheel is large, for example with the same grinding wheel as above, the grinding wheel life is 30 hours, the cost of grinding wheel/h will be 12,000 VND/hour. However, when the diameter of the grinding wheel is small, that is, extending the life of the grinding wheel, the cutting speed is very low and leads to very low grinding productivity.

Thus, there exists an optimal grinding wheel life value, or the optimum exchanged diameter of grinding wheel, for which the cost of grinding is minimal. In addition, there exists an optimal grinding wheel life value at which the profits of the grinding process are greatest.

In reality, mechanical production conditions in Vietnam, most facilities use universal surface grinders - the rotation speed of the spindle is usually constant and most use Hai Duong grinding wheel - The grinding wheel has good cutting properties, low initial cost and is currently exported a lot. With a surface grinders, The exchanged diameter grinding wheel (or the grinding wheel life) is a parameter that directly affects the productivity and cost of a surface grinding job. In addition, the production facilities in our country often have the habit of using a grinding wheel until it can no longer be used, that is, grinding until the stone is worn to the edge of the rock clamp, because it is often assumed that using a grinding wheel such as so will save. At that time, the small diameter of the grinding wheel and the low cutting speed resulted in reduced grinding productivity, increased surface grinding costs and reduced economic efficiency. For that reason, the determination of the optimum grinding wheel life (or the optimum exchanged diameter of the grinding wheel) is aimed at achieving the minimum level of grinding cost or the maximum processing profit. Important practical meaning in grinding production in our country.

From the aforementioned analysis, it is possible to improve the efficiency of the final surface grinding process (increasing productivity or reducing the cost of grinding) by determining the optimum exchanged diameter of grinding wheel when replacing (or the optimal life) of a grinding wheel.

In addition to the aforementioned problem, the fact that grinding machining shows that the use of cool fluid is a very effective measure to reduce the heat when grinding, reduce the wear of the stone and lead to improved productivity and quality of the grinding process [48]. In addition, studies in [16] and [69] show that the dressing mode has a great influence on the topography of the grinding wheel and thereby affects the cutting ability of the grinding wheel. Thus, in addition to the measure to determine the optimum exchanged diameter of the grinding wheel as mentioned above, to improve the efficiency of the surface grinding process (improve productivity, quality assurance and reduce machining costs) This can be done by determining the optimal cooling lubrication and dressing mode if possible.

From the above issues, the author chooses the topic " research to improve the efficiency of final surface grinding process " for my thesis.

2. Purpose of the study

The purpose of the study is to study to improve the economic and technical efficiency of the final surface grinding through parameters of the exchanged diameter of grinding wheel, cooling lubrication mode, cutting mode and dressing mode. From that, we can choose a reasonable set of technology parameters to reduce costs while improving productivity and surface quality.

3. Methodology and scope of the study

3.1. Methodology and subjects of study

- *Methodology of study*: Theoretical research combined with experimental research.

Theoretical research: Surveying the published research results, analyzing the issues that need further study, thereby determining the research direction, subjects, objectives and scope of the thesis. Analysis and selection of experimental planning methods to reduce the number of experiments. Building a calculation model to determine the optimun exchanged diameter of the grinding wheel.

Experrimental research: Experimental study of the effect of parameters on the economic - technical efficiency of the process of the final surface grinding. From that, determine the parameters of cooling technology, cutting mode and dressing mode. At the same time verify the calculation model to determine the optimum exchanged diameter of the grinding wheel.

- **Research subjects:** Technology of final grinding by circumference of griding wheel with the object of experiment is 90CrSi steel through quenching with Hai Duong griding wheel.

90CrSi steel is a commonly used alloy tool steel for making thin and plate plates and cutting tools such as: Air compressor valves, clutch leaves, disc brakes, stamping dies, injection molds, pestle - press mortar, cutting tool and angular… and often hardened to meet the requirements of anti-abrasion and final grinding is the final finishing. While in Vietnam, traditional grinding wheel, especially Hai Duong grinding wheel - a type of grinding wheel with good cutting properties, a reasonable initial cost and a lot of exports - is now commonly used on the surface grinding machines.

3.2. Research scope:

- Determining the optimum exchanged diameter of surface grinding wheel by theory and experiment;
- Determine the appropriate cooling lubrication mode when surface grinding by experiment;
- Determine the dressing by experiment.

4. The meaning of the research

4.1. Scientific significance

- Analyze the cost of the surface grinding process and then build a calculation model to determine the optimum exchanged diameter;
- Clarify the effect of cooling lubrication and cutting mode on surface roughness and cutting force; dressing to roughness, cutting force, flatness tolerance, durability and machining productivity when grinding 90CrSi steel with Hai Duong grinding wheel;
- The results of the study will contribute to perfect the theory of the grinding process (especially final surface grinding) and as a scientific basis for other works to optimize the grinding process..

4.2. Practical significance

Research results can be used as a reference for teaching, scientific research and practical applications to improve productivity and quality while reducing the cost of final surface grinding.

5. New points (new contributions) of the study

- Proposing a model to determine the cost of surface grinding to calculate the optimal diameter to replace the lowest cost by theoretical and empirical verification;

- Assessing the effect of cooling lubrication and cutting mode when surface grinding to choose a reasonable set of parameters when grinding 90CrSi steel with Hai Duong grinding wheel;
- Assessing the effect of the technology of dressing when surface grinding to choose a reasonable set of parameters when grinding 90CrSi steel with Hai Duong grinding wheel.

6. Thesis structure

Cấu trúc của luận án được trình bày gồm: Mở đầu, 04 chương và kết luận chung.

Chapter 1. Overview of surface grinding

Chapter 2. Theoretical foundations of surface grinding and method of building experimental models.

Chapter 3. Empirical research to determine the cooling lubrication mode, cutting mode and dressing mode.

Chapter 4. Research to determine the optimum exchanged diameter of grinding wheel.

General conclusions and further research directions.

CHƯƠNG 1. OVERVIEW OF THE SURFACE GRINDING

1.1. Features and diagrams of surface grinding

1.2. Overview of research issues

1.2.1. The study of the effect of cutting mode

1.2.2. The study of the dressing parameters

1.2.3. Studies on cooling lubrication mode

1.2.4. The study of the determination cost of surface grinding process

1.3. Research orientation

The economic and technical requirements of a surface grinding process are usually assessed through surface roughness, surface stress, abrasive strength, cutting force, peeling yield, energy consumption, etc. Therefore, the durability of the grinding wheel and the machining capacity depend on the technical requirements and especially the process parameters such as cutting mode, cooling lubrication mode, dressing mode. The longer the life of ginding and the greater its productivity, the basic grinding time, the time to adjust the machine decreases, the smaller the dressing time. That is, the life of grinding wheel durability and machining productivity will directly affect the grinding cost.

The analysis of the grinding cost calculation model also shows that, among the cost components of the grinding process, the cost of basic grinding time accounts for the largest proportion, followed by the cost of machine calibration, cost of fixing and removing details and cost of stone repair time. In particular, the cost of fixing and removing details depends mainly on the skill of workers, the detail size and the type of production. The remaining cost components depend on the technical requirements, stone age and machining productivity. In order to reduce the cost of the grinding process, it is necessary to apply technological measures to increase the cutting speed to increase the productivity, increase the durability of the grinding wheel while ensuring technical requirements to reduce the cost of grinding time. basic cost, machine calibration cost and cost of dressing time.

In order to increase the durability of the grinding wheel and the productivity to reduce the cost of the surface grinding process while ensuring the technical requirements of the surface grinding process such as surface roughness, flat tolerance, the thesis selected three solutions, detail:

- Determine the cooling lubrication mode and cutting mode appropriately or optimally;
- Determine the reasonable or optimal dressing mode;
- Determine the diameter of the grinding wheel when exchang (the optimum exchanged diameter of grnding wheel).

Conclusion Chapter 1

1. Grinding is a very complex process. The quality of the grinding process is usually assessed through criteria such as surface roughness, machining productivity and cost of the grinding process. These criteria are influenced by many factors such as grinding mode, dressing mode, solution type and cold smooth mode, cutting force, thermal cutting ...
2. Surface roughness, cutting force, machining productivity, durability are often used as targets to evaluate the grinding process.
3. It is possible to reduce the cost of grinding operations by reducing the basic grinding time, reducing the cost of dressing, calibrating the machine and improving the durability of the grinding wheel by replacing the abrasive with the value of the diameter of the

exchanged diameter or optimization to increase the speed of cutting of the grinding wheel to increase machining productivity, reduce the basic grinding time thereby improving the economic efficiency of the grinding process..

4. Choosing the right or optimal lubrication mode is one of the measures to increase the quality of grinding (reducing surface roughness, increasing machining accuracy) as well as reducing grinding costs. So far, although there has been a lot of research on determining the appropriate cooling mode or optimization when grinding, there is still a lack of research to determine a reasonable cooling mode when grinding hard 90CrSi steel.
5. The process of repairing a grinding wheel is carried out in three steps: Repairing rough, repairing fine and repairing grinding wheel without using knives. However, up to now, there has been no research on a reasonable dressing mode when surface grinding hard 90CrSi steel when dressing with the three steps mentioned above. Therefore, it is necessary to conduct research to determine the appropriate rock repair regime when using the dressing process through these three steps.

CHAPTER 2. THEORETICAL FOUNDATIONS OF SURFACE GRINDING AND METHOD OF BUILDING EXPERIMENTAL MODELS

2.1. Characteristics of the surface grinding process

2.1.1. The process of creating Chips when grinding

2.1.2. Cutting edge

2.1.3. Supply arc length

2.1.4. Underformed chip thickness

2.1.5. Dressing process

2.1.5.1. Dressing

2.1.5.2. Dressing tools

2.1.5.3. Topography of grinding wheel

2.1.6. Lubrication cooling

2.1.6.1. Heat cutting during grinding

2.1.6.2. The role of cool fluid

2.1.6.3. Type of cool fluid

2.1.6.4. Cooling lubrication methods are often used when grinding

2.2. Several indicators evaluate the grinding process

2.2.1. Wear and life of grinding wheel

2.2.1.1. Wear of grinding wheel

2.2.1.2. Life of grinding wheel

2.2.2. Surface roughness when grinding

2.2.3. Cutting force when grinding

2.2.4. Material remove rate

2.2.5. Straight surface ginding

2.3. Model to improve the efficiency of flat grinding

2.3.1. Diagram and basis of the study to improve the efficiency of the final grinding process

2.3.2. Select input parameters

2.3.3. Solutions to improve the efficiency of the grinding process

2.4. Model the experimental system and select the research equipment

2.4.1. General requirements for the experimental system

2.4.2. Connection diagram of experimental equipment

2.4.3. Selection of equipment and workpiece

2.4.3.1. Ginding machine

2.4.3.2. Workpiece

2.4.3.3. Grinding wheel

2.4.3.4. Cool solution

2.4.3.5. Dressing tool

2.4.3.6. Testing tools

2.5. Experimental design methods and experimental planning

2.5.1. Choose method

2.5.2. Steps follow the Taguchi method.

2.5.3. The optimization steps use Grey Relational Analysis – GRA.

Conclusion Chapter 2

1. Has analyzed and selected the input parameters and outputs of the study. Input parameters of the flat grinding process include: Table speed (V_B), cross feed (S_d), depth of cut (f_d), cutting time (t_c), amount of excess machining ($a_{e, tot}$) , cost of machine hours ($C_{m,h}$); Hardness of workpiece (HRC), required tolerance (δ), workpiece density (Mp); Initial grinding wheel diameter (D_0), grinding wheel width (W_{gw}), the amount of abrasive stone after each durability cycle (W_{pd}), the purchase price of a grinding grinding

wheel ($C_{đm}$), life of grinding wheel (T_w); Depth of dressing (a_{ed}), feed rate of dressing (S), number of dressing (n); Solution type, irrigation method, solution concentration (ND), solution flow rate (LL). Output parameters include: Surface roughness Ra, cost for grinding per part $C_{t,\,p}$ and the optimum exchanged diameter of grinding wheel $D_{e,op}$.

2. Proposed model to improve the efficiency of the flat grinding process with 03 solutions including: Using a reasonable cooling lubrication mode, using an optimal dressing mode and grinding with an optimum exchanged diameter of grinding wheel. These solutions will be presented in the next chapters of the thesis.
3. Has built, connected testing systems, selected measuring devices that meet the research objectives.
4. The Taguchi methods and Taguchi methods with GRA are applied in experimental design and planning to allow the selection of the most number of parameters to survey but the least number of experiments. This method is suitable for research and evaluation requirements.

CHAPTER 3. EMPIRICAL RESEARCH TO DETERMINE THE COOLING LUBRICATION MODE, CUTTING MODE AND DRESSING MODE

3.1. Experiments determine the cooling lubrication mode and reasonable cutting mode

3.1.1. Select parameters and testing conditions

Experimental levels of parameters ND, LL, S_d, VB and f_d.

Parameters \ Levels	1	2	3	4
Coolant flow LL (l/min)	5	10	15	20
Coolant concentration ND (%)	1	2	3	4
Cross feed S_d (mm/parth)	6	8	10	12
Table speed V_B (m/min)	6	8	10	12
Depth of cut f_d (mm)	0,005	0,01	0,015	0,02

3.1.2. Determined according for surface roughness Ra

3.1.2.1. Influence level of the parameters

When the coolant concentration ND increases, the average surface roughness value ($\overline{Ra}$) decreases and reaches the lowest value when the concentration of ND = 4%. This can be explained by the fact that when increasing the concentration of cool solution, the friction between stone and abrasive part decreases so rough surface decreases.

When coolant flow LL increased, the rough surface roughness value ($\overline{Ra}$) increased then decreased, ($\overline{Ra}$) achieved the smallest value when LL flow was 5 l/min. This can be explained as follows: When the flow increases, the friction between the grinding wheel and the workpiece reduces heat cutting, longer sharp stones increase the surface roughness, the durability of the grinding wheel increases. However, when the flow increases to a certain extent, the cutting heat hardly decreases, the increase in lubrication reduces friction and reduces surface roughness..

The cross feed S_d increases, the surface roughness increases then decreases. Surface roughness value is achieved when S_d = 6 mm/parth. This is explained as follows: As the amount of vertical toolpath increases, the width of the part of the part in contact with the grinding wheel increases, resulting in increased surface roughness. If you continue to increase the amount of tool feed, the increased cutting force will result in the cutting edges breaking into smaller, finer cutters that reduce surface roughness.

Table speed V_B increases, surface roughness decreases then increases and then decreases. The roughness value is achieved when V_B = 8m/min. This is explained by the increase in table speed when processing high hardness materials (58 ÷ 60 HRC) causing the abrasive grains on the surface of the grinding stone to become smaller sized particles, reducing the surface roughness. However, the increase in table velocity, the accidental breakage of the abrasive particles, at this time the impact of the shape and dynamics of the abrasive particles mainly caused surface roughness to increase and then decrease again.

Depth of cut when grinding increases surface roughness then decreases and then increases and reaches the smallest value at t = 0.01 mm. This can be explained by the fact that when increasing the depth of cut increases the cutting force, the cutting ability of the grinding wheel is reduced, especially when processing high-hardness materials (58 ÷ 60 HRC), surface abrasives grinding wheel are broken into smaller sized particles that reduce surface roughness. However, as the grinding depth of cut increases, the accidental breakage of the grinding wheel is mainly influenced by the shape and dynamics of the grinding wheel, causing surface roughness to increase and then decrease..

3.1.2.2. Determine the reasonable mode

Ramin: ND = 4%, LL = 5 l/min, S_d = 6 mm/parth, V_B = 8 m/min, f_d = 0,01 mm.

3.1.2.3. Predictive calculation

(0,323 -0,09) µm $\leq$ $(Ra)_{op}$ $\leq$ (0,323 + 0,09) µm

Experimental results: Ra = 0,348 µm. This value is 7.18% different from the predicted value.

3.1.3. Determined according to norm normal force F_y

3.1.3.1. Determine the influence of the parameters.

As the coolant concentration ND increases, cutting force $\bar{F}_y$ decreases then increases. The value of the cutting force $\bar{F}_y$ is the smallest when the concentration ND = 3%. This can be explained: When increasing the concentration of coolant solution, the friction between the grinding wheel and the grinding element decreases, so the cutting force is reduced. The further concentration increases, the more concentrated the solution makes the chip harder to escape. At this time, the increase in shear force due to chips is greater than the decrease due to the increase in the concentration of coolant solution. The result is increased shear force.

When coolant flow LL increases, cutting force $\bar{F}_y$ decreases then increases. The value of the cutting force $\bar{F}_y$ is achieved when the flow rate LL = 15 l/min. This is explained as follows: As the flow increases, the chip cleaning capacity increases, better lubrication leads to cutting forces. However, as the flow continues to increase, the decrease in cooling lubrication leads to an increase on cutting force $\bar{F}_y$.

The Cross feed S_d increases, cutting force $\bar{F}_y$ increases. The value of shear force $\bar{F}_y$ is achieved when S_d = 6mm/HT. This is explained as follows: As the amount of longitudinal tooling increases, the surface area of the grindstone involved in cutting (contacting the workpiece surface) increases, resulting in an increase in the width of the cutting layer leading to increased cutting force $\bar{F}_y$.

Table speed V_B increases, cutting force $\bar{F}_y$ increases. The value of cutting force $\bar{F}_y$ is achieved when V_B = 6 m/min. This is explained as follows: When the table speed increases the contact time between the grinding wheel and the workpiece surface decreases, leading to an increase on cutting force $\bar{F}_y$.

Depth of cut increases while cutting force $\bar{F}_y$ increases. Cutting force $\bar{F}_y$ reaches the smallest value when f_d = 0.005 mm. This is explained as follows: As the cutting depth increases, the thickness of the cutting layer increases resulting in increased cutting force.

3.1.3.2 Determine the reasonable mode

The values and corresponding levels of the survey parameters for the goal of achieving the minimum Fy value are: ND = 3%, LL = 15 l/min, S_d = 6 mm/parth, V_B = 6 m/min, f_d = 0,005 mm.

Experimental verification: Fy = 43,3 N.

3.1.4. Multi-objective problem with surface roughness and minimum normal cutting force by GRA with Taguchi method

The reasonable set of parameters to satisfy both Ra and F_y is at least: ND3/LL3/S_d1/V_B1/f_d1, corresponding to: ND = 3%, LL= 15 l/min, S_d = 6 mm/parth, V_B = 6 m/min, f_d = 0,005 mm.

η_{op} =0,8188; Ra_{op} = 0,5036 µm

Experimental results show: Ra = 0,527 µm, F_y = 43,3N

3.2. Empirical research to identify reasonable dressing regime

3.2.1. Selection of parameters and experimental conditions

Experimental levels of parameters S, a_{edr}, n_r, a_{edf}, n_f và n_{non}.

Levels / Parameter	1	2	3	4
Dressing feed rate S [m/min]	1,6	1,8	-	-
Coarse dressing depth a_{edr} [mm]	0,015	0,02	0,025	0,03
Coarse dressing times n_r [lần]	0	1	2	3
Fine dressing depth a_{edf} [mm]	0,005	0,01	-	-
Fine dressing times n_f [times]	0	1	2	3
Non-feeding dressing n_{non} [times]	0	1	2	3

3.2.2. Determined according to surface roughness criteria

3.2.2.1. Impact analysis

Fine dressing times made the biggest contribution to Ra (31%), followed by coarse dressing times (25.2%), non-feeding dressing

(23.7%), coarse dressing times (10.7%), fine dressing depth (8.9%) and finally dressing feed rate (0.5%).

Coarse dressing depth a_{edr} increases, the surface roughness increases, then decreases and then increases and reaches the smallest value at level 3 (0.025 mm). This can be explained as follows: Initially, when increasing coarse dressing depth increases the initial undulating height of the grinding wheel, leading to a decrease in the number of dynamic cutting edges which increases the roughness of the surface. However, as coarse dressing depth continues to increase, the initial undulating height of the grinding wheel continues to increase. On the other hand, the workpiece has a high hardness so the cutting edges will be broken to return to the initial undulating height of cutting aegth, the height of the cutting blade increases the number of dynamic cutting edges resulting in surface roughness. reduction. If the coarse dressing depth is still increased, the accidental breakage of the abrasive particles makes the surface roughness difficult to control, which can increase or decrease.

Coarse dressing times increased, the surface roughness increased and then dropped sharply and reached the smallest value at level 4 (three times). This is explained by the fact that as the Coarse dressing times increases, the initial undulating height of the grinding wheel increases, the conditions of chip removal increase, the easier the grinding wheel makes roughening of the surface sharply reduced..

Fine dressing depth a_{edf} increased, the surface roughness increased and reached the smallest value at level 1 (0.005 mm). The reason is that when increasing the fine dressing depth, the initial undulating height of the rock increases the number of dynamic blades. So the surface roughness increased.

Fine dressing times n_f increases, the surface roughness decreases and then increases and reaches the smallest value at level 2 (once). Obviously, when the fine dressing, the number of dynamic cutting edges increases compared to that of not repairing the stone, increasing the cutting ability of the grinding wheel leading to reduced surface roughness. However, increasing the fine dressing times, the initial undulating height of the edges and the original height of the edges decreases, the space containing small chips should be quickly filled. Therefore the cutting properties of the grinding wheel are reduced. In addition, the hardness of the processed material is high, the friction between the adhesive and the machining surface increases, so the surface roughness increases.

Non-feeding dressing n_{non} increases, the surface roughness decreases and reaches the lowest value at level 4 (three times). This is explained by the increase in the non-feeding dressing n_{non}, the increase in the number of dynamic blades, which means that the non-feeding dressing is, resulting in reduced surface roughness..

Dressing feed rate S increases, the roughness of the surface increases and reaches the smallest value at level 1 (1.6 m/min). The reason is that when increasing the number of edges cutting tools reduces the number of dynamic blades, the cutting ability of the edges decreases and the surface roughness increases.

3.2.2.2. Define a reasonable set of stone repair parameters

a_{edr} = 0,025 mm (a_{edr}3), n_{edr} = 3 times (nr4), n_{non} = 3 times (n_{non}4), n_f = 1 times (n_f2), a_{edf} = 0,005 mm (a_{edf}1) và S = 1,6 m/min (S1) are the optimal levels and values of the dressing parameters to achieve Ra_{min}

3.2.2.3. Calculate the prediction surface roughness value

Ra_{OP} = 0,2505 µm

Experimental results: Ra = 0.286 µm, 6.98% difference from the prediction.

3.2.3. Determined according to norm normal force

3.2.3.1. Impact analysis

The fine dressing times accounted for the largest contribution (33.4%), followed by coarse dressing depth (30.6%), the non-feeding dressing (20.5%), the dressing feed rate (12.2%), the coarse dressing depth (3.2%) and the fine dressing times (0.1%).

The Coarse dressing depth increases, then the normal force Fy decreases then increases and then decreases and reaches the smallest value at level 2 (0.02 mm). This can be explained as follows: When increasing the coarse dressing depth, the dynamic blade density decreases so the cutting force is reduced. However, if the coarse dressing depth continues to increase, adding to the accidental shattering properties of the abrasive grain when processing high hardness materials, the original height of the blade is reduced, the number of dynamic blades increases, so the cutting force increases or decreases randomly.

The Coarse dressing times n_r increases, then Fy decreases then increases and reaches the smallest value at level 3 (2 times). This can be explained by the increase in the coarse dressing times, the initial height of the cutting edge increases, the chip exit condition increases, the cutting force is sharply reduced. However, if you continue to increase the Coarse dressing times, the processing of high hardness materials causes the abrasive particles to become smaller particles, the number of dynamic cutting edges increases, the condition of chip removal reduces, friction between the stones. and the increased workpiece increases the cutting force.

The Non-feeding dressing increases, then Fy increases sharply then decreases slightly and reaches the smallest value at 1 (no runs). This is explained: The more the Non-feeding dressing, the number of dynamic cutting edgess increases, the original height of the grinding wheel decreases, the finer the grinding surface is, the condition of the chip exit is reduced, the friction between the grinding wheel and the limb. increased machining parts increase the cutting force. When increasing the non-feeding dressing to a certain value, the initial height of the grinding wheel is almost zero, the cutting force hardly changes much.

The fine dressing depth increases, Fy decreases and reaches the smallest value at level 2 (0.01 mm). This is explained by the fact that when increasing the fine dressing depth, the density of dynamic blades decreases, so the cutting force is reduced.

The fine dressing times increases, Fy increases and reaches the smallest value at level 1 (1 times). This is explained by the fine dressing times, the number of dynamic blades increases resulting in increased cutting force.

The dressing feed rate increases, Fy decreases and reaches the smallest value at level 2 (1.8 m/min). This is explained by the increase in the number of toolpaths for the cutting of grinding wheel, the reduced number of blades for cutting forces.

3.2.3.2. Determine a reasonable set of dresing parameters

Set of reasonable dressing parameters to achieve the minimum cutting force: Rough dressing 2 times with a_{edr} = 0,02 mm, S = 1,8 m/ph.

3.2.3.3. Calculate predictive value of Fy

Fy_{OP} = 49,89 N

Experimental results F_y = 53 N, diffrent wrong 6,0% with the predicted value.

3.2.4. Determined according to the life of grinding wheel T_w

3.2.4.1. Impact analysis

The Coarse dressing times has the strongest influence on the life of the grinding wheel (85,373%), followed by the coarse dressing depth (11,839%), followed by the non-feeding dressing (1,665%), the fine dressing times (0.807%), the dressing feed rate (0.315%), and finally the fine dressing depth has the least impact (0.001%).

The coarse dressing depth increases, the life of the grinding wheel decreases then increases and reaches the maximum value at 0.015 mm (a_{edr}1). This can be explained as follows: When increasing coarse dressing depth, the original height of the grinding wheel increases, the sharpness of the edges increases (the radius of the cutting edges) makes the grinding wheel easier to cut. Increasing the coarse dressing depth, the cutting edges will be broken to return to the state of the original undulating height of small edges (especially when grinding 90CrSi material with high hardness), the height of the cutting edges is reduced, the fast grinding chip fills in the gaps between the more abrasive particles, resulting in reduced durability. If you continue to increase the coarse dressing depth, due to the accidental breakage of the grain, the life of the grinding wheel can also increase or decrease randomly.

The implementation of rough dressing significantly increases the durability of the grinding wheel compared to no rough dressing. This confirms the need for dressing. Increasing the coarse dressing times made the cutting ages decrease and then increased and reached the maximum value at 3 times (n_r4). Increasing the Coarse dressing times the durability tends to not increase much. However, the more times the rough dressing is repaired, the longer the life of grinding wheel. The increase in the number of Coarse dressing times makes the life of the grinding wheel increase or decrease, the number of dynamic or reduced cutting edges, the cutting force or increase increases the life of grinding wheel decreases or increases.

The fine dressing significantly reduces the lìe of grinding wheel abrasion compared to that of no fine dressing and the life of the grinding wheel reaches the maximum value when there is no fine dressing (n_f1). Increasing the fine dressing times, the life of grinding wheel changes little. This is explained by the fact that when making fine dressing, the initial undulating height of the grinding wheel is reduced compared to that after fine dressing, the surface of the grinding wheel is finer, the space of the Chips contains decreases making the durability of the life of grinding wheel decrease.

The fine dressing depth increases, the life of grinding wheel decreases and the durability reaches the maximum value at level 1 (n_f1). As the fine dressing depth increases, the initial undulating height of the grinding wheel decreases compared with that after the repair of rough dressing, the chip clearance space decreases, leading to reduced the life of grinding wheel.

The practice of non-feeding dressing significantly reduces the sharpness of the sharpening grinding wheel compared to Non-feeding dressing and the life of the grinding wheel reaches the maximum value when the non-feeding dressing is at 1 (n_{non}1 - no times). Increasing the non-feeding dressing, the life decreases and then increases slightly. This is explained by the more non-feeding dressing, the finer the grinding surface is, the more space the chips contain is narrower, the life decreases..

The dressing feed rate increases, the life of the grinding wheel decreases and the maximum value when the dressing feed rate is at level 1 (1.6 m/min). This is explained by the increase dressing feed rate, the reduced chip space reduces the durability.

3.2.4.2. Determine a reasonable set of dressing parameters

T_{wmax}: Rough dressing 3 times with a_{edr} = 0,015 mm, S = 1,6 m/min.

3.2.4.3. Calculate predicted T_w value

(39,29 - 2,86) min ≤ T_{wop} ≤ (39,29 + 2,86) min

Experimental results T_w = 37,2 min, diffrent wrong 5,32% with anticipation.

3.2.5. Determined according to flatness tolerance criteria

3.2.5.1. Impact analysis

Coarse dressing depth is most strongly affected (39.9%), followed by the Non-feeding dressing (24.8%), fine dressing depth (22.2%), and coarse dressing times (7,1%), the Fine dressing times (5.9%) and the last amount of the dressing feed rate was the smallest (0.1%).

The coarse dressing depth increases, $\overline{Fl}$ decreases then increases and reaches the smallest value at 0.025 mm (aedr3). This can be explained as follows: When the coarse dressing depth increases, the initial undulating height of the cutting edges increases, the chip clearance space increases, the cutting conditions are improved, resulting in a reduced flat tolerance. However, if continued to increase the coarse dressing depth, the initial undulating height of the cutting edges increases, the cutting edges are more likely to be broken into smaller cutting edges when machining, reducing chip clearance space, cutting conditions limit flatness tolerance increases.

Have rough dressing make the flatness tolerance compared to not rough dressing. The number of times to fix rough stone Coarse dressing times increases, $\overline{Fl}$ increases then decreases and reaches the smallest value at 3 times (n_r4). This is explained by the fact that when rough dressing, the original height of the grinding wheel increases, the space for chip removal and removal is larger, making the chip easier to exit, the cutting easier to make the flatness tolerance compared with not rough dressing.

The non-feeding dressing increases then $\overline{Fl}$ increases then decreases sharply and reaches the smallest value at no times ($n_{non}1$). The more non-feeding dressing, the grinding surface is flatter makes the cutting ability of the grinding surface reduced, the flatness tolerance increases.

Have fine dressing makes the flatness tolerance larger than not correct. Increasing the fine dressing times, the flatness tolerance is smaller than no repair. If the fine dressing times is further increased, the flatness tolerance is greater than that of no fine dressing. The flatness tolerance reaches the minimum value at two times of the fine dressing times (n_f3). When increasing the fine dressing times, the number of dynamic cutting edges increases, so the fltness tolerance decreases. However, increasing the fine dressing times, the initial undulating height of the cutting edges decreases, the cutting ability of the grinding surface decreases so the flatness tolerance increases.

The fine dressing depth increased, $\overline{Fl}$ decreased and reached the smallest value at 0.01 mm ($a_{edf}2$). This is because when increasing the fine dressing depth, the initial undulating height cutting edges increases, leading to an increase in the cutting ability of the grinding wheel, resulting in a reduction in the flatness tolerance.

Dressing feed rate increased, $\overline{Fl}$ increased and reached the smallest value at 1.6 m/min (S1). As the cutting edges increases, the dressing feed rate decreases, the cutting edges decreases resulting for the flatness tolerance increase.

3.2.5.2. Determine a reasonable set of dressing parameters

Fl_{min}: Rough dressing 3 times with a_{edr} = 0,025 mm, fine dressing 2 times with a_{edf} = 0,01 mm, non-feeding dressing 3 times with the same S = 1,6 m/min.

3.2.5.3. Calculate predicted Fl value

(7,13-2,66) µm ≤ Fl_{op} ≤ (7,13+2,66) µm

Experimental results Fl = 6,68 µm, diffrent wrong 6,31% with anticipation.

3.2.6. Determined according to merterial removal rate norms

3.2.6.1. Impact analysis

The coarse dressing times is the most influential (75.32%), followed by the non-feeding dressing (11.85%), the coarse dressing depth (5.31%), the dressing feed rate (3.83%), fine dressing depth (3.06%) and finally, the fine dressing times has the smallest impact (0.63%).

The coarse dressing depth increases, $\overline{MRR}$ increases then decreases and reaches the maximum value at 0.02 mm (a_{edr}2). This can be explained as follows: As the coarse dressing depth increases, the initial undulating height of the cuting edges increases, increasing the capacity of containment and chip removal leads to increased productivity. If you continue to increase the coarse dressing depth, the original height of the edges increases, making the cutting edges more likely to break to return to the original undulating height of the small edges, the ability to store and remove chips, making machining productivity decrease.

Having rough dressing make increases the $\overline{MRR}$ to no. The coarse dressing times increases, $\overline{MRR}$ decreases then increases and reaches the smallest value at 1 time (n_r2). Obviously, the productivity does not increase according to a certain rule due to the randomness of the dressing process.

The non-feeding dressing increased, $\overline{MRR}$ decreased sharply and reached the maximum value when non-feeding dressing (n_{non}1) was performed. The more times non-feeding dressing, the grinding surface is finer, this reduces the ability of the cuting edges, reducing $\overline{MRR}$.

Having fine dressing make the $\overline{MRR}$ smaller than no fine dressing and $\overline{MRR}$ reaches the maximum value when there is no fine dressing (0 times - $n_{non}1$). Increasing the fine dressing times, $\overline{MRR}$ increases. Having fine dressing, the original height of the cutting edges of grain is reduced compared to only the repair of rough dressing, the space for containment and chip removal decreases, the cutting capacity of the grinding wheel decreases resulting in reduced $\overline{MRR}$. If the fine dressing times is increased, the number of dynamic cutting edges increases, increasing the productivity. However, the more fine dressing times repaired, the lower the original height of the cutting edges compared to just rough dressing, resulting in reduced $\overline{MRR}$. To sum up, the productivity increases when the fine dressing times is increased, but still lower than that of not repairing.

The fine dressing depth increases, $\overline{MRR}$ increases and reaches the smallest value at 0.01 mm ($a_{edf}2$). This is because when fine dressing depth, the initial undulating height increases, leading to the increased cutting capacity of the grinding wheel, resulting make $\overline{MRR}$ increase.

The dressing feed rate increased, $\overline{MRR}$ decreased and reached the smallest value at 1.6 m/min (S1). As the dressing feed rate increases, the number of dynamic cutting edges decreases, the cutting decreases in resulting reduced $\overline{MRR}$.

3.2.6.2. Determine a reasonable dressing regime

MRR_{max}: Rough dressing once with a_{edr} = 0,02 mm, S = 1,6 m/min, no fine fine dressing and non-feeding.

3.2.6.3. Calculate predicted MRR value

(7,867-0,53) mm^3/s ≤ MRR_{op} ≤ (7,867+0,53) mm^3/s

Experimental results MRR = 7,63 mm^3/s, diffrent wrong 3,01% with anticipation.

3.2.7. Multi-objective problem of surface roughness and flatness tolerance when dressing

The goal is to find dressing mode for both Ra_{min} and Fl_{min}

3.2.7.1. Perform GRA value

The non-feeding dressing is the strongest impact (30%), followed by the nine dressing times (28.4%), coarse dressing depth (22.2%), coarse dressing times (9.7 %), fine dressing depth (8.5%) and final amount of dressing feed rate (1.2%).

3.2.7.2. Determine the reasonable level of the survey parameters to achieve both goals Ra_{min} and Fl_{min}

Ra_{min} and Fl_{min}: a_{edr} = 0,025 mm, n_r = 3 times, n_{non} = 3 times, n_f = 2 times, a_{edf} = 0,01 mm, S = 1,6 m/min

3.2.7.3. Calculate GRA values and Ra and Fl values corresponding to the reasonable level of dressing parameters

η_{op} = 0,88; Ra_{op} = 0,365 µm; Fl_{op} = 7,13 µm

3.2.8. Multi-objective problem to all four goals surface roughness Ra, flatnes tolerance Fl, merterial removal rate MRR and life of grinding wheel Tw when dressing

The goal is to find a reasonable dressing mode for all four goals: Ra_{min}, F_{lmin}, MRR_{max} và Tw_{max}.

3.2.8.1. Analysis GRA number

The coarse dressing times has the strongest impact (65.4%) on the goals, followed by non-feeding dressing (11.63%), fine dressing times (9.19%), fine dressing depth (6.7%), coarse dressing depth (5.48%), and finally dressing feed rate (1.76%). However, in order to GRA number, the coarse dressing depth has the strongest influence and the fine dressing depth has the smallest effect..

3.2.8.2. Determine the level and values of dressing parameters for all four goals Ra_{min}, Fl_{min}, MRR_{max} and T_{wmax}

Ra_{min}, Fl_{min}, MRR_{max} and Tw_{max}: Dressing models: a_{edr}3/n_r4/n_{non}4/n_f3/a_{edf}2/S1, a_{edr} = 0,025 mm, n_r = 3 times, n_{non} = 3 times, n_f = 2 times, a_{edf} = 0,01 mm, S = 1,6 m/min.

3.2.8.3. Calculate GRA values and values of Ra, Fl, MRR and Tw corresponding to the reasonable level of dressing parameters

η_{op}=0,7793; Ra_{op} = 0,365 µm; Fl_{op} = 7,13 µm; MRR_{op} = 5,03 mm^3/s; Tw_{op} = 29,88 ph

Conclusion Chapter 3

1. Applying Taguchi method to evaluate the effect of cooling lubrication and cutting mode on surface roughness and cutting force and the effect of dressing mode on surface roughness, flatness tolerance, life of grinding wheel, meterial removal rate when surface grinding.
2. Select lubrication parameters and cutting mode when grinding 90CrSi steel with Hai Duong grinding wheel.
3. Selection of dressing parameters when surface grinding 90CrSi steel with Hai Duong grinding wheel.

CHAPTER 4. RESEARCH TO DETERMINE THE OPTIMUM EXCHANGED DIAMETER OF GRINDING WHEEL

4.1. Analyze the cost of surface grinding

4.1.1. Determine the cost of grinding for a part

4.1.2. Determining the time of grinding a part t_{gc}

4.2. Investigate the effect of some parameters on the cost of surface grinding

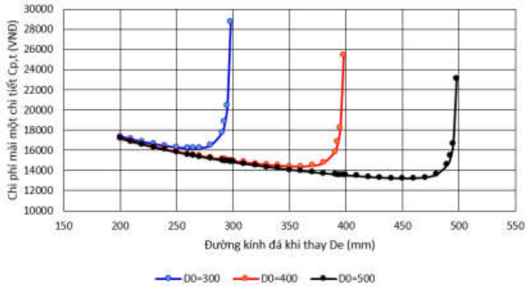

Fig 4.9. Effect exchanged diameter to the cost of grinding for a part.

4.3. Investigate the influence of some parameters on the optimum exchanged diameter

4.3.1. Define the objective function and develop an implementation plan

4.3.2. Evaluate the effects of the parameters

4.3.2.1. Evaluate the effects of survey parameters on $D_{e,op}$.

4.3.2.2. Regression analysis - variance

$$\begin{aligned} De,op &= -1,29 + 0,95384D_0 - 67,02a_{ed} + 0,0045T_w - 51,1W_{pd} \\ &- 1,2.10^{-5}C_{mh} - 1,7.10^{-5}C_{đm} - 0,1522D_0{*}a_{ed} + 0,001055D_0{*}T_w \\ &- 0,1560D_0{*}W_{pd} + 1,175.10^{-7}D_0{*}C_{mh} - 3,67.10^{-8}D_0{*}C_{đm} + 1,436a_{ed}{*}T_w \\ &+ 344\,a_{ed}{*}W_{pd} + 0,000159a_{ed}{*}C_{mh} - 5.10\text{-}5a_{ed}{*}C_{đm} - 1,1.10^{-6}T_w{*}C_{mh} \\ &+ 3,487.10^{-7}T_w{*}C_{đm} - 5,2.10^{-5}W_{pd}{*}C_{đm} + 5,47.10^{-11}C_{mh}{*}C_{đm} \end{aligned} \quad (4.28)$$

4.4. Verify the model to determine the optimum exchanged diameter by experiment

4.4.1. Experimental conditions

4.4.2. How to conduct the experiment

4.4.3. Experimental results

With empirical original grinding diameter D_0 = 300mm, this optimal value is approximately 265 mm. This result is 1.95% different from the theoretical calculation (270.17 mm). Using according to optimum exchanged diameter make increases MRR 40.98%, increases the life of grinding wheel 52.47%, reduces the grinding time by 22.38% and ultimately leads the cost of grinding for a part 14.14%.

4.5. Application of an optimum exchanged diameter model with an optimal dressing and cooling mode

If applying the optimal dressingmode, the optimal cooling mode and the optimum exchanged diameter, MRR increases 49.53%, life of grinding wheel 51.52%, grinding time decreases 22, 35%, grinding costs decreased by 24.07% and grinding costs decreased by 9.93% compared to only applying the optimum exchanged diameter (14.14%).

Conclusion Chapter 4

1. The cost of grinding a part was analyzed, and the impact of eight parameters were investigated (initial diameter of grinding wheel D_0, grinding wheel width W_{gw}, total depth of dressing, Rockwell hardness of workpiece HRC, life of grinding wheel Tw, wear of grinding wheel W_{pd}, the cost of the hour C_{mh} and the cost of a grinding wheel C_{dm} to grinding cost.
2. Analyzed and surveyed the effects of the eight parameters mentioned above and their interaction to the optimum exchanged diameter to get the smallest grinding cost. The analysis results show that the initial diameter of grinding wheel D_0 is the most influential parameter, whereas, Rockwell hardness HRC and grinding width do not significantly affect the optimum exchanged diameter..
3. Based on quantitative analysis, a regression model has been calculated that calculates the optimum exchanged diameter with a reliability of 99.99%:

$$
\begin{aligned}
De{,}op = &– 1{,}29 + 0{,}95384D_0 – 67{,}02a_{ed} + 0{,}0045T_w – 51{,}1W_{pd} \\
&– 1{,}2.10^{-5}C_{mh} – 1{,}7.10^{-5}C_{đm} – 0{,}1522D_0*a_{ed} + 0{,}001055D_0*T_w \\
&– 0{,}1560D_0*W_{pd} + 1{,}175.10^{-7}D_0*C_{mh} – 3{,}67.10^{-8}D_0*C_{đm} \\
&+ 1{,}436a_{ed}*T_w + 344\, a_{ed}*W_{pd} + 0{,}000159a_{ed}*C_{mh} – 5.10\text{-}5a_{ed}*C_{đm} \\
&– 1{,}1.10^{-6}T_w*C_{mh} + 3{,}487.10^{-7}T_w*C_{đm} –5{,}2.10^{-5}W_{pd}*C_{đm} \\
&+5{,}47.10^{-11}C_{mh}*C_{đm}
\end{aligned}
$$

4. Experimental results show that the model for calculating the optimum exchanged diameter value proposed in chapter 2 is suitable. Experiments show that the optimum exchanged

diameter is 265 mm, the difference is very small (1.95%) compared to the optimum exchanged diameter calculated by theory (270.17 mm).

5. Compared to real production experience, when applying the exchanged grinding wheel model at the optimum exchanged diameter, MRR increase 40.98%, the life of grinding wheel increase 52.47%, the time for grinding detailed 22,38% and ultimately results in a 14.14% reduction in the cost of grinding a part compared to changing grinding wheel according to usage habits.
6. If combined with optimum exchanged diameter, cooling lubrication mode and optimal dressing mode increases MRR 49.53%, life of grinđing wheel increase 51.52%, grinding time a part reduce 22.35% and grinding costs reduce 24.07%.

GENERAL CONCLUSIONS AND FURTHER RESEARCH DIRECTIONS

1. General conclusions

1. Proposing a model to determine the cost of surface grinding process to calculate the optimum exchanged diameter to replace the lowest cost by theoretical and empirical verification;
2. Assessing the effect of cooling lubrication and cutting mode when grinding flat to choose a reasonable set of parameters when grinding finely on the experimental object of 90CrSi steel with Hai Duong grinding wheel;
3. Assessing the effect of of the technology of dressing when grinding flat to choose a reasonable set of parameters when grinding finely on the experimental object of 90CrSi steel with Hai Duong grinding wheel.

2. Further research directions

Although this study has come up with one of solutions to improve the efficiency of the surface grinding process, it is still necessary to continue studying the effect of cooling lubrication, cutting mode and dressing mode on muscles, physical properties of surface layer after grinding. In addition, it is necessary to study to improve the efficiency when grinding with CBN grinding wheel.

LIST OF PUBLISHED WORKS RELATED TO THE THESIS

1. Vu Ngoc Pi, **Luu Anh Tung**, Le Xuan Hung and Banh Tien Long, *"Cost Optimization of Surface Grinding Process"* Journal of Environmental Science and Engineering A 5 (2016), pp. 606-611.
2. Vu Ngoc Pi, **Luu Anh Tung**, Le Xuan Hung and Nguyen Van Ngoc, *"Experimental Determination of Optimum Exchanged Diameter in Surface Grinding Process"*, Journal of Environmental Science and Engineering A 6 (2017), pp. 85-89.
3. Vu Ngoc Pi**, Luu Anh Tung**, Tran Thi Hong, Nguyen Thi Thanh Nga, Le Xuan Hung, Banh Tien Long, *"An optimization of exchanged grinding wheel diameter when surface grinding alloy tool steel 9CrSi",* materials Today: Proceedings, The 9th International Conference of Materials Processing and Characterization, ICMPC-2019 Science Direct, Volume 18, Part 7, pp. 2225-2233, **ScienceDirect, Scopus**, 2019.
4. Thi-Hong Tran, **Anh-Tung Luu**, Quoc-Tuan Nguyen, Hong-Ky Le, Anh-Tuan Nguyen, Tien-Dung Hoang, Xuan-Hung Le, Tien-Long Banh and Ngoc-Pi Vu, *"Optimization of Replaced Grinding Wheel Diameter for Surface Grinding Based on a Cost Analysis",* Metals, 2019, pp.448, **SCIE.**
5. **Luu Anh Tung**, Vu Ngoc Pi, Do Thi Thu Ha, Le Xuan Hung and Tien Long Banh, *"A Study on Optimization of Surface Roughness in Surface Grinding 9CrSi Tool Steel by Using Taguchi Method*", International Conference on Engineering Research and Applications 1-2 December, Thai Nguyen, Vietnam, pp. 100-108, 2018, **Scopus**.
6. **Luu Anh Tung**, Vu Ngoc Pi, Vu Thi Lien, Tran Thi Hong, Le Xuan Hung, Banh Tien Long, *"Optimization of Dressing Parameters of Grinding Wheel for 9CrSi tool Steel using the Taguchi Method with Grey Relational Analysis*", **Materials Science and Engineering**, 635, pp. 12030, 2019, **Scopus**.