

# International Journal on Advanced Science, Engineering and Information Technology



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Frequency: 6 issues per year

DOI : 10.18517

ISSN : 2088-5334

e-ISSN : 2460-6952

## Important Dates :

Paper Submission Date: Any time



2018 Acceptance Rate: 18.20 % | 2019 Acceptance Rate: 17.85 %

Online Publication Date: Last date of February, April, June, August, October, December

International Journal on Advanced Science, Engineering and Information Technology is indexed in Elsevier Scopus database

# International Journal on Advanced Science, Engineering and Information Technology

HOME	ABOUT	LOGIN	REGISTER	SEARCH	CURRENT
ARCHIVES	ANNOUNCEMENTS				

Home > Archives > **Vol 9, No 1 (2019)**

## Vol 9, No 1 (2019)

### Table of Contents

#### Articles

<a href="#">Design and implementation of a Marking Strategy to Increase the Contactability in the Call Centers, Based on Machine Learning</a>	PDF
<i>Leonel Hernandez, Henner Guzman, Jose Ospino, Jean Freyle, Andri Pranolo</i>	1-7
<a href="#">Requirements Engineering (RE) Process for The Adaptation of The Hospital Information System (HIS)</a>	PDF
<i>Sofianiza Abd Malik, Azlin Nordin, Reem Nasser Al-Ehaidib</i>	8-17
<a href="#">A Data Driven Approach to Wind Plant Control using Moth-Flame Optimization (MFO) Algorithm</a>	PDF
<i>Muhammad Azizan Md Idris, Mok Ren Hao, Mohd Ashraf Ahmad</i>	18-23
<a href="#">Uniform Distorted Scene Reduction on Distribution of Colour Cast Correction</a>	PDF
<i>Muhamad Lazim Talib, Mohamad Faizul Nasruddin, Siti Norul Huda Sheikh Abdullah</i>	24-31
<a href="#">Factors Affecting Information Quality in the Malaysian Public Sector</a>	PDF
<i>Erizamsha Hassan, Zawiyah M. Yusof, Kamsuriah Ahmad</i>	32-38
<a href="#">Analysis of Image Transmission using MIMO-Alamouti Space-Time Encoding</a>	PDF
<i>Manpreet Kaur, Lavish Kansal, Navjot Kaur, Gurjot Singh Gaba, Dharma P. Agrawal</i>	39-45
<a href="#">21st Century Skills Mastery Amongst Science Foundation Programme Students</a>	PDF
<i>Punia Turiman, Tengku Siti Meriam Tengku Wook, Kamisah Osman</i>	46-53
<a href="#">Evaluation of Packet Tracer Application Effectiveness in Computer Design Networking Subject</a>	PDF
<i>- Ambiyar, Surfa Yondri, Dedy Irfan, Meilani Putri, Mahesi Agni Zaus, Syaiful Islami</i>	54-59
<a href="#">Competency Discovery System: Integrating the Enhanced ID3 Decision Tree Algorithm to Predict the Assessment Competency of Senior High School Students</a>	PDF
<i>Jestoni Vasquez, Benilda Eleonor Comendador</i>	60-65
<a href="#">Visual Analytics: Design Study for Exploratory Analytics on Peer Profiles, Activity and Learning Performance for MOOC Forum Activity Assessment</a>	PDF
<i>Mohammad Fadhli Asli, Muzaffar Hamzah, Ag Asri Ag Ibrahim, Alter Jimat Embug</i>	66-72
<a href="#">Segmentation of Carpal Bones Using Gradient Inverse Coefficient of Variation with Dynamic Programming Method</a>	PDF
<i>Sadiyah Jantan, Anuar Mikdad Muad, Aini Hussain</i>	73-80
<a href="#">Artificial Intelligence in Diagnosing Tuberculosis: A Review</a>	PDF

<i>Syeda Shaizadi Meraj, Razali Yaakob, Azreen Azman, Siti Nuralain Mohd Rum, Azree Shahrel Ahmad Nazri</i>	81-91
<a href="#">Rate Movie App: Implementation of K-Nearest Neighbors Algorithm in the Development of Decision Support System for Philippine Movie Rating and Classification</a>	<a href="#">PDF</a>
<i>Ian Dexter M. Siñel, Benilda Eleonor V. Comendador</i>	92-99
<a href="#">Performance Analysis of Loss Multilevel Quantization on the Secret Key Generation Scheme in Indoor Wireless Environment</a>	<a href="#">PDF</a>
<i>Mike Yuliana, Wirawan Wirawan, Suwadi Suwadi</i>	100-108
<a href="#">Co-existence Issue in IoT Deployment using Heterogeneous Wireless Network (HetNet): Interference Mitigation using Cognitive Radio</a>	<a href="#">PDF</a>
<i>Ayaskanta Mishra</i>	109-120
<a href="#">Indonesia Composite Index Prediction using Fuzzy Support Vector Regression with Fisher Score Feature Selection</a>	<a href="#">PDF</a>
<i>Zuherman Rustam, - Nurrimah, Rahmat Hidayat</i>	121-128
<a href="#">A Resilient Environment through The Integration of CCA and DRR: An Overview of Existing Challenges</a>	<a href="#">PDF</a>
<i>Nuwan Dias, Georgina Clegg, Dilanthi Amaratunga, Richard Haigh</i>	129-135
<a href="#">A Comparative Analysis of Web Search Query: Informational Vs. Navigational Queries</a>	<a href="#">PDF</a>
<i>Nuhu Yusuf, Mohd Amin Mohd Yunus, Norfaradilla Wahid</i>	136-141
<a href="#">Considerations for Cost Estimation of Software Testing Outsourcing Projects</a>	<a href="#">PDF</a>
<i>Fatin Filzahti Ismail, Rozilawati Razali, Zulkefli Mansor</i>	142-152
<a href="#">Real-Time Wheat Classification System for Selective Herbicides Using Broad Wheat Estimation in Deep Neural Network</a>	<a href="#">PDF</a>
<i>Arif Ullah, Nazri Mohd Naw, Anditya Arifianto, Imran Ahmed, Muhammad Aamir, Sundas Naqeeb Khan</i>	153-158
<a href="#">Prediction of Hourly Cooling Energy Consumption of Educational Buildings Using Artificial Neural Network</a>	<a href="#">PDF</a>
<i>Alaa Abdulhady Jaber, Ahmed Saleh, Hussein Fouad Mohammed Ali</i>	159-166
<a href="#">FPGA Implementation of Hand-written Number Recognition Based on CNN</a>	<a href="#">PDF</a>
<i>Daniele Giardino, Marco Matta, Francesca Silvestri, Sergio Spanò, Valerio Trobiani</i>	167-171
<a href="#">Integrating Business Intelligence and Analytics in Managing Public Sector Performance: An Empirical Study</a>	<a href="#">PDF</a>
<i>Nur Hani Zulkifli Abai, Jamaiah Yahaya, Aziz Deraman, Abdul Razak Hamdan, Zulkefli Mansor, Yusmadi Yah Jusoh</i>	172-180
<a href="#">A Rehabilitation Gaming System for Cognitive Deficiencies: Design and Usability Evaluation</a>	<a href="#">PDF</a>
<i>Ahmed Mohammed Elakloul, Nor Azan Mat Zin</i>	181-187
<a href="#">The Impact of Employee Involvement and Empowerment in Lean Manufacturing System Implementation towards Organizational Performances</a>	<a href="#">PDF</a>
<i>Eida Nadirah Roslin, Shamsuddin Ahmed, Mohamad Asmidzam Ahamat, Mohd Zaki Bahrom, Norazlin Ibrahim</i>	188-193
<a href="#">An Algorithm for Plant Disease Visual Symptom Detection in Digital Images Based on Superpixels</a>	<a href="#">PDF</a>
<i>Itamar F. Salazar-Reque, Samuel Gustavo Huamán, Guillermo Kemper, Joel Telles, Daniel Diaz</i>	194-203
<a href="#">Dynamic Message Puzzle as Pre-Authentication Scheme in Wireless Sensor Networks</a>	<a href="#">PDF</a>
<i>Farah Afianti, Wirawan Wirawan, Titiek Suryani</i>	204-212
<a href="#">Lexical Disambiguation (CKBD): A Tool to Identify and Resolve Semantic Conflicts Using Context Knowledge</a>	<a href="#">PDF</a>
<i>Said Al Tahat, Kamsuriah Ahmad</i>	213-219
<a href="#">Multilayer Perceptron (MLP) and Autoregressive Integrated Moving Average (ARIMA) Models in Multivariate Input Time Series Data: Solar Irradiance Forecasting</a>	<a href="#">PDF</a>
<i>Devi Munandar</i>	220-228
<a href="#">A Modified Event Grouping Based Algorithm for The University Course Timetabling Problem</a>	<a href="#">PDF</a>

<i>Velin Spasov Krlev, Radoslava Stankova Krleva, Sachin Kumar</i> <u>Wi-Fi Signals Database Construction using Chebyshev Wavelets for Indoor Positioning Systems</u>	229-235 PDF
<i>Anvar Narzullaev, Zahriddin Muminov, Gafurjan Ibragimov</i> <u>New Functions and Evaluation for Learning Effects of Acceleration Experiment Support Software</u>	236-241 PDF
<i>Takahiro Hoshino, Yuki Ota, Kohei Tomaru, Yoshio Hamamatsu, Takafumi Komuro</i> <u>IT Risk Identification and Evaluation: a Case Study on XYZ University</u>	242-249 PDF
<i>Daniel Albertivan, Hendryantono Limantara, Reza Annisa Rachmadiati, Nico Surantha, Adik Wedsa Pamungkas</i> <u>Updated Goals, Operators, Methods, and Selection Rules (GOMS) with Touch Screen Operations for Quantitative Analysis of User Interfaces</u>	250-257 PDF
<i>Pisal Setthawong, Rachsuda Setthawong</i> <u>Active Teaching Techniques for Engineering Students to Ensure The Learning Outcomes of Training Programs by CDIO Approach</u>	258-265 PDF
<i>Tien Quoc Le, Thu Thi Anh Do</i> <u>An Analysis of Black Fill Artefacts Noise Removal on GRD Products Sentinel-1 Data</u>	266-273 PDF
<i>Haris Suka Dyatmika, Katmoko Ari Sambodo, Rahmat Arief</i> <u>Urban Sprawl Mapping and Land Use Change Detection Analysis</u>	274-280 PDF
<i>M. Lenin Sundar, C. Arun Prasath, H. Elstin Rosario, K. Tamilselvan</i> <u>Regional Cooperation towards Effective Multi-Hazard Early Warnings in Asia</u>	281-286 PDF
<i>Kinkini Hemachandra, Richard Haigh, Dilanthi Amaratunga</i> <u>The Location-allocation Decision under The Dynamic Increment of Demand for Selecting The Local Distribution Centers to Face Sumatra Megathrust: Study Case of Padang City</u>	287-292 PDF
<i>Liperda Rahmad Inca, Sirivongpaisal Nikorn</i> <u>Concreting Workmanship in Indonesia Study Case: Padang City, West Sumatra, Indonesia</u>	293-299 PDF
<i>Eka Juliafad, Iskandar G. Rani, Fitra Rifwan, Yose Fajar P</i> <u>Experimental Analysis on the Ultrasound-based Mixing Technique Applied to Ultra-low Sulphur Diesel and Bio-oils</u>	300-306 PDF
<i>Anh Tuan Hoang, Viet Dung Tran</i> <u>Effect of Mechanical Tumbling Parameters on Surface Roughness and Edge Radius of Medical Grade Cobalt Chromium Alloy</u>	307-313 PDF
<i>Is Prima Nanda, Mohd Hazwan Hassim, Mohd Hasbullah Idris, Muhammad Hafiz Jahare, Andril Arafat</i> <u>Effect of Firing Temperatures on Physico - Mechanical Properties of Clay Bricks Containing Reeds</u>	314-320 PDF
<i>Ghazwan Abdulsamad Salman, Shakir Ahmed Salih</i> <u>A Study on the Breaking and Winnowing Machine for Cocoa Beans at Small Industrial Scale in Vietnam</u>	321-328 PDF
<i>Huy-Bich Nguyen, Duy-Lam Pham, Van-Lanh Nguyen</i> <u>A Software Development Methodology for Secure Web Application</u>	329-335 PDF
<i>Junho Lee, Jungwoong Woo, Cheongan Lee, Kyungsoo Joo</i> <u>SMS-Based ICT Tool for Knowledge Sharing in Agriculture</u>	336-341 PDF
<i>Dario H. Galeon, Paul G. Garcia Jr., Thelma D. Palaoag</i> <u>Application of Road Engineering NSPM Action Programs on Sub-National Roads in Indonesia</u>	342-349 PDF
<i>Anastasia Caroline Sutandi, Agus Taufik Mulyono</i> <u>Sedimentation Dynamics of the Lower Part of Sentolo Formation at Niten Stream Traverse, Girimulyo, West Progo</u>	350-356 PDF
<i>Setyo Pambudi, Vijaya Isnaniawardhani, Winantris Winantris, Adjat Sudradjat</i> <u>Compressive and Flexural Strength Behavior of Ultra-high Performance Mortar Reinforced with Cellulose Nano-fibers</u>	357-364 PDF
<i>Steve W.M Supit, Tomoya Nishiwaki</i> <u>Physicochemical Properties of Egg Yolk Powder from Eggs of Different Types of Bird</u>	365-372 PDF
<i>Lim Jing Wei, Abbas F.M. Alkarkhi, Nurul Huda</i> <u>Addition of Spirulina as Feed Supplement in The Ration on Production</u>	373-378 PDF

and Eggs Quality of The Sentul Chickens

*Tuti Widjasuti, Endang Sujana, Roostita Lobo Balia*

379-383

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Published by INSIGHT - Indonesian Society for Knowledge and Human Development

# Effect of mechanical tumbling parameters on surface roughness and edge radius of medical grade cobalt chromium alloy

*by* Is Prima Nanda

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**Submission date:** 28-Aug-2020 05:23PM (UTC+0800)

**Submission ID:** 1375398742

**File name:** hness\_and\_edge\_radius\_of\_medical\_grade\_cobalt\_chromium\_alloy.pdf (1.3M)

**Word count:** 4787

**Character count:** 25739

## Effect of Mechanical Tumbling Parameters on Surface Roughness and Edge Radius of Medical Grade Cobalt Chromium Alloy

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**Abstract**— Smoothly polished prosthesis surface is a crucial requirement in medical application and important feature that determine the proper response to corrosion and biocompatibility in the human body. Tumbling is one of the pre-polishing processes that can be conducted in order to improve the surface roughness of the machined prosthesis. However, the using of ceramic media for the tumbling process in medical application is not widely reported. This study was conducted to investigate the effect of mechanical tumbling parameters on the surface roughness of medical grade CoCr alloy by using alumina (Al<sub>2</sub>O<sub>3</sub>) based ceramic media. The experiment was performed with a different level of rotational speed (35, 55, and 75 rpm) and soaking time (4, 6 and 8 hours) of the tumbling process. The surface roughness of specimens before and after the process was measured using Mitutoyo Formtracer CS-5000 and the edge radius was measured using Olympus SZX9 microscope integrated with I-solution Lite software. It was figured that 6 hours tumbling time at 55 rpm showed the most significant reduction (32 %) in surface roughness (Ra) of the CoCr alloy specimen, while 8 hours tumbling time at 75 rpm showed the highest effect on the edge radius of the specimen at 63 % increment.

**Keywords**— CoCr alloys; medical application; mechanical tumbling; surface finish.

### I. INTRODUCTION

Artificial bones, known as a prosthesis, is commonly made of polymer, composite ceramic and metal [1]. Surface roughness properties play an important role in the fabrication of prosthesis as the materials need excellent tolerate contact with the bones and tissues in the body [2]. The improper surface roughness of the prosthesis may find difficulties in joint with adjacent bones and other tissues, which will cause the loosening of the implant [3]. On the other hand, the rough surface also will contribute to high wear rate and corrosion, where the ion release from these processes may go to the surrounding tissue and cause allergic and problematic symptoms [4]. Thus, it is essential that these prostheses need to undergo the proper surface finishing process so that the desired surface finish can be achieved based on the clinical standard [5]. Key factors for the prosthesis or biomaterials is to have low wear, low friction, and smooth surface and perfect clearance [6]. Nowadays, cobalt chromium (CoCr) alloys were used in

such applications as hip and knee prosthesis due to its excellent properties instead of biocompatibility material.

Numerous research has been done in some modification in implant surface to improve their incorporation in bone tissue [7]. Different parameters of surface roughness varies depend on several medical requirements including bio-tolerance and ability to perform a better combination for the artificial joints application [8].

Tumble finishing or other terms which known as tumbling or rumbling [9] is a method for smooth out and polishing a rough or irregular surface on relatively small work parts. In the metalworking field, burr and a sharp edge are common remaining by-product after machining operation [10]. Metal tumbling is widely used in industry to burnish, deburring, cleaning, radius adjustment, de-flash, descale, eliminating rust, polishing, brightening, surface hardening, prepare parts for further finishing, and separating die cast runners [11].

Tumbling operation consists of loading a charge composed by the components to be finished, media, water, and compound within a rotating barrel. A horizontal of a



multi-dimensional barrel is occupied with the parts which are then rotated which represent the tumbling process. The rotation transmits to the granular material a shear force able to carry up the charge until a critical state is reached: at this stage, a portion of the material, previously involved in a solid motion, collapses in an avalanche flow namely active layer. This way some phenomena can occur. These phenomena depend upon several aspects such as the physical and geometrical properties of the granular elements, the shape and the typology of the barrel and the process parameters. Different granular flows can be observed when one of these aspects changes.

Tumbling media which have cutting ability can get rid of burrs and can smoothen work part surfaces [11]. The impact force of the abrasive on the work part rises as the larger media pieces presence. Thus the effectiveness of the abrasive can improve the work part surface to be more shine. A very important function of the medium is to separate parts during the debarring, cutting, surface improving or burnishing operations. The media parts volume ratio is normally used to control the amount of part-on-part contact which will occur in a vibratory or tumble finishing operation. At low ratios, considerable part-on-part contact occurs, while at higher ratios part-on-part contact is limited. Media has the unique ability to scrub surfaces and physically assist compounds in their cleaning function [11]. Both abrasive and non-abrasive media are effective in this. They can remove organic soils, scale, and other inorganic residues. Fig. 1, 2, and 3 shows the type of media.



Fig. 1 Aluminium Oxide Media



Fig. 2 Ceramic Media



Fig. 3 Silicon Carbide Media

One of the most important properties necessary in tumbling media is hardness [12]. The media must be harder than the material it is to grind, polish, or remove. From Table 1, the aluminum oxide-based ceramic media shows that the higher value of hardness properties compared to media of plastic. Based on the hardness properties, the selection of aluminum oxide-based ceramic media for the tumbling finishing process is rational for the surface roughness reduction of CoCrMo.

TABLE I  
PROPERTIES COMPARISON BETWEEN PLASTIC MEDIA AND ALUMINIUM OXIDE BASED CERAMIC MEDIA

Mechanical Properties	Plastic Media	Aluminum Oxide based Ceramic Media
Density, gm/cc	2.6	3.89
Compressive Strength, Mpa	1200	2600
Hardness, Kg/mm <sup>2</sup>	1019	1440
Maximum Use Temperature, °C	650	1750

In the tumbling process, bath solutions are also added to mass finishing processes to prevent scratched and black on sample surface from embedded abrasives. The solutions are usually broken up into four types which are deburring and finishing, burnishing, cleaning, and water is stabilizing [13]. Deburring and finishing compounds are mainly designed to suspend the small particles created when deburring and abrading parts. They are also designed to keep workpieces clean and inhibit corrosion. Burnishing compounds are designed to enhance brightness and to develop certain colors after mass finishing. Cleaning compounds are usually dilute acids or soaps designed to remove soil, grease, or oil from the incoming parts. They also provide corrosion resistance for ferrous and nonferrous parts. Water stabilizer is used in conjunction with water to maintain a consistent water hardness and level of metal ions. When combined with compounds, the water not only carries the abrasives and keeps the media clean, but also acts as a cushion to help protect the parts [14].

Tumbling finishing provide a deburring process which used to deburr, clean, radius, polish, brighten and prepare parts for further finishing. Burrs are undesired projections of material beyond the edges of the workpiece due to plastic deformation during machining. Burrs of excessive size often



must be removed for the part to be handled safely, assembled, or function effectively. Besides that, the tumbling process deburrs an estimated 30-50% of all hand size and smaller metal piece parts [15]. The agitated tumbling barrel causes the solution to circulate and lubricate the media in a smooth tumbling action. Burrs are slowly abraded away. Usually, different shapes are used in the same load to reach into every geometry of the part [16].

The rotational speed of the barrel will produce a centrifugal force that acts on the components in the barrel which clinging them on the barrel's wall. At some point, the components bump and starting collide with each other. This movement will create a polishing process on the workpieces [17]. The changes in these variables produced a different value of surface roughness. Several investigations have been studied on the characterization of the rotating tumbling motions.

Henein et al. [18] developed a tool, called the bed behavior diagram, allowing navigating the map of the possible granular motions as a function of the filling percentage and the rotational speed. The bed behavior strictly depends upon the particular charge and the employed barrel. Boateng [19] attempted the identification of the kinematics: the change in velocity profiles deeply modifies flow behavior from pseudoplastic to Newtonian to dilatant types. Boschetto and Veniali [20] found the relationship between granular material density, responsible of the dilatancy, and the velocity gradient within the active region: in this work the rolling and the cascading regime are considered as the most suitable for tumble polishing. Mellmann [21] analyzed and modeled the transition behaviors in a simplified way highlighting that in correspondence of rolling-cascading transition no mathematical model is known. Some experimental investigations have been carried out to empirically observe the kinematics of the rotating cylinder adopting different measuring techniques. Pérez-Alonso and Delgadillo [22] used digital image processing to validate 2DDem code: simulation of ideal spheres are very close to experimental values. Nakagawa [23] employed noninvasive nuclear magnetic resonance imaging to determine axial segregation of particles within rotating cylinders. Bbosa et al. [24] reconstructed the motion of mono-sized glass balls within a small tumbling mill: experiments were undertaken using the positron emission particle tracking. Domblesky et al. [25] and Hashimoto et al. [26] presented force-based models of workpiece-media contact to predict material removal rates. Potentially powerful Discrete Element Methods (DEM), which model media particles as discrete entities and tracks their interactions with the workpiece, are being pursued by Uhlmann et al. [27] and Spelt's research group [28]. While the DEM approach is computationally expensive and reliant on difficult to obtain material properties when fully realized, it has the potential to predict media-workpiece impact modes, forces, and frequencies, thus providing insights on material removal mechanisms and expected finishes.

It is proved that tumbling can improve the surface finish of the product significantly [29]. However, these processes have not received the same level of scientific scrutiny as other material removal processes and thus remain in need of comprehensive, predictive, and systematic modeling

investigations. In this paper, the effect of mechanical tumbling on the surface roughness of CoCr alloy were reported.

## II. MATERIAL AND METHOD

For research is used an ASTM F75 CoCr alloy solid cut into the rectangular with the tapered angle. Table 2 summarizes the composition of CoCr alloy.

TABLE II  
THE COMPOSITION OF COCr ALLOY IN WEIGHT PERCENT

Ni	N	Co	Cr	Ti	Mo
<0.5	<0.25	57.4 - 65.0	27.0 - 30.0	<0.1	5.0 - 7.0
Al	Fe	Mn	W	C	Si
<0.1	<0.75	< 1.0	<0.2	<0.35	< 1.0

The machining process that involved in this study was tumbling machining which provides polishing, cleaning, burnishing and deburring toward the surface of medical grade CoCr alloy. CoCr alloy specimens were cut by using Wire Electrical Discharge Machining (EDM Wire Cut). These specimens were ground by using Bainpol-VTD grinder in order to remove the oxidation layer from the specimen. Then the specimens were cleaned before undergo tumbling process. The dimension of the CoCr alloy specimen is shown in Fig. 4.

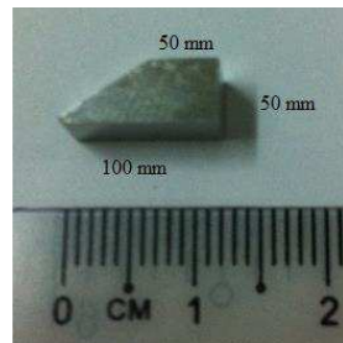


Fig. 4 The dimension of CoCr alloy specimen

The manipulated variables in this experiment were speed and time taken for the tumbling process, which was determined based on the literature. The tumbling barrel was filled with CoCr alloy specimens, Al<sub>2</sub>O<sub>3</sub> based ceramic media, and sodium hydroxide solution. The rotational speed of the tumbler machine was controlled at 35 rpm, 55 rpm and 75 rpm which gives the three-speed variation for this experiment. The speed was adjusted by the connected inverter that can variate the motor speed of the tumbling machine. Running time were set at three variations; 4 hours, 6 hours, and 8 hours.

Aluminum based ceramic media was used for this tumbling process, and it is fixed for every run of the experiment. These media were filled for half full of the 3-litre barrel volume. There were two different cutting type of ceramic media used, which are angle cut and straight cut as

shown in Fig. 5 and Fig. 6 respectively. The 100ml of sodium hydroxide solution was measured and filled in the tumbling barrel as it is necessary for the CoCr alloy specimens to experience the same effect in every run of the tumbling process.



Fig. 5 Angle cut ceramic media



Fig. 6 Straight cut ceramic media

In overall, there are nine runs of the experiment were conducted with difference parameter setup. The measurement of surface roughness and edge radius was taken before and after the tumbling process. The steps involved for the tumbling process on CoCr alloy are as follows:

- The tumbling barrel is half full filled with the six pieces of CoCr alloy specimen and the Aluminum Oxide based ceramic media.
- The tumbling barrel is filled with sodium hydroxide solution, and the barrel's cover is tighten.
- The speed of 35 rpm ran tumbler machine for about 4 hours.
- The work pieces and media is rinsed with fresh water.
- All of the steps above were repeated but with different time taken off 6 hours and 8 hours.
- All of the steps above were repeated with different rotational speed of 55 rpm and 75 rpm.

Mitutoyo Formtracer CS-5000 had been used to measure the roughness of specimen surface as shown in Fig. 7. The average Ra values were taken as an indicator of the surface roughness of the specimen. On the other hand, the edge radius was measured by using Olympus SZX9 Microscope integrated with Resolution Lite software as shown in Fig. 8.

The changes of edge radius are related to the significant burr removal.

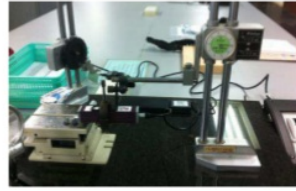


Fig. 7 Mitutoyo Formtracer CS-5000



Fig. 8 Olympus SZX9 Microscope

### III. RESULTS AND DISCUSSION

The results of the effect of rotational speed and tumbling time on the changes in surface roughness and edge radius were presented and discussed in this section.

#### A. Analysis of Surface Roughness

The surface roughness measurement were taken before and after the tumbling process as it is necessary to determine the difference in response values that being affected by the selected parameters. The average surface roughness different and percentage of surface roughness reduction of the specimens is calculated for every run of the experiment. The experiment result is summarized in Table 3.

TABLE III  
EXPERIMENT RESULT OF SURFACE ROUGHNESS, RA DIFFERENCE AND PERCENTAGE OF SURFACE ROUGHNESS REDUCTION

Run	Time Taken, (hour)	Speed, (rpm)	Surface Roughness, Ra difference, ( $\mu\text{m}$ )	Percentage of Surface roughness reduction, (%)
1	4	35	0.0375	5.439
2	4	55	0.0680	16.408
3	4	75	0.0025	11.380
4	6	35	0.0950	30.370
5	6	55	0.1565	32.328
6	6	75	0.0930	26.488
7	8	35	0.0140	5.417
8	8	55	0.0655	18.545
9	8	75	0.0080	1.887

The result is illustrated in Fig. 9 that represents the graph of average surface roughness difference versus rotational speed. The three lines that represents the selective time shows the same graph trend which the average difference of surface roughness is increasing initially from 35 rpm to 55 rpm and then become drop when proceeding to higher speed which is 75 rpm. This means that all of the surface roughness value, Ra of CoCr alloy specimens has decreased but the reduction of the Ra value is different for every run of the tumbling process. The highest average Ra difference value is obtained when the speed parameters is set at 55 rpm.

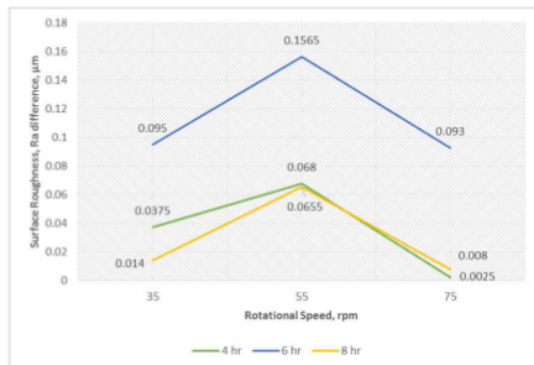


Fig. 9 Graph of surface roughness difference against rotational speed

The component in the tumbling barrel begin to move in a regular and orderly manner from 35 rpm to 55 rpm. This action provided an effective cutting deburring and polishing on the CoCr alloy specimens which caused the value of the average Ra difference become increase. There is relative movement of media against parts within the bulk of the load or in the regions adjacent to the walls of the barrel. This means the reduction of the Ra values is become higher due to this tumbling condition as the specimen and media were colliding effectively for the polishing and deburring purpose.

When going for the further rotational speed which is up to 75 rpm, it showed that the average difference in Ra value become drop which means the reduction of Ra value become lower. This happen is due to component movement behavior in the tumbling barrel which being swept upwards only to fall back against the parts below. The CoCr alloy specimens were not polished well by the media at this such speed. This condition is not effective due to their behavior that being severely damaged by colliding with one another and the media seems to be more wear as they experience a vigorous collision between themselves and the barrel's wall. In other words, this phenomenon is known as impingement where the colliding motion occur in the non-effective slide zone in the tumbling barrel [30]. The higher rotational speed caused the component in the barrel experience more centrifugal force that made them to be cling at the barrel's wall. Thus this make the component to be sliding and bumping on the narrow slide zone of the movement behavior in the barrel that contribute to the slow cutting rate.

Time taken of the tumbling process would give effect towards the surface roughness of CoCr alloy specimens where the variation of this parameter was made by three levels which is 4, 6 and 8 hours of tumbling process.

Initially, the average Ra difference value becomes increasing as the cutting rate become high when the time is set from 4 hours to 6 hours of tumbling process. The increment in cutting rate is due to the frequent collision between the abrasive media and the specimens that occur in the tumbling barrel [31]. The media obviously has their ability to make the cutting and polishing action towards CoCr alloy specimens in the beginning duration of tumbling process which 4 to 6 hour.

A tumbling process extended until 8 hours, the average Ra difference value turned out to decrease which means the less reduction of surface roughness value. This happened is because of the repetitive colliding motion of the component in the barrel that effects the abrasive media to experience more wear. The component happened to be more frequent to collide with themselves and the barrel's wall for a long time taken of the tumbling process. Thus the cutting and polishing rate becomes less that results in the less reduction of the surface roughness value.

### B. Analysis of Edge Radius

The selective tumbling parameters give significant effect towards the final edge radius values to be much higher compared with initial edge radius values which means burr removal occur onto the CoCr alloy specimens. The result is summarized in Table 4 and illustrated in Fig. Ten that represents the graph of average edge radius difference against speed with the time taken as constant. While Fig. 11 shows the difference of edge radius before and after tumbling process.

TABLE IV  
EXPERIMENT RESULT OF EDGE RADIUS DIFFERENCE AND PERCENTAGE OF EDGE RADIUS INCREMENT

Run	Time Taken, (hour)	Speed, (rpm)	Average Edge Radius the difference, (mm)	Percentage of Edge Radius increment, (%)
1	4	35	0.0045	1.622
2	4	55	0.0355	4.354
3	4	75	0.0970	13.550
4	6	35	0.0145	19.088
5	6	55	0.0595	31.776
6	6	75	0.1065	38.517
7	8	35	0.0250	29.353
8	8	55	0.0680	36.535
9	8	75	0.1640	63.077

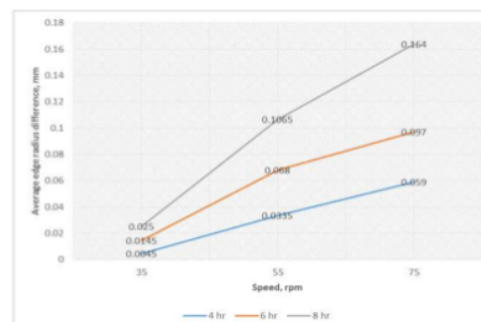


Fig. 10 Graph of average edge radius difference versus speed



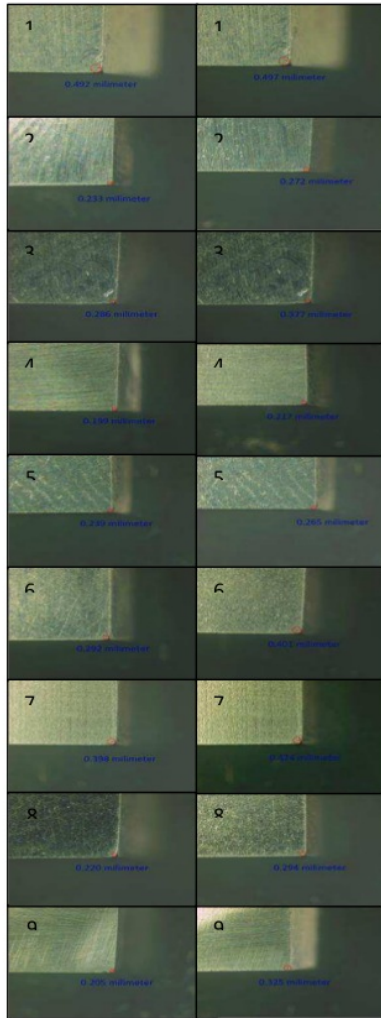


Fig. 11 Edge radius of the sample before and after the tumbling process for Run 1 – Run 9

The tribological behavior of the interactions between the media and specimen is complex. In this study, repetitive collision contact is developed and used to investigate the interface behavior of the tumbling process. The increasing of speed caused the specimen and media in the tumbling barrel to collide more vigorously within themselves. This situation provides slow but significant burr removal — the longer time is taken for the tumbling process, the more removing burr to increase [32]. When going for the further speed up to 75 rpm, the average edge radius difference becomes increasing steadily which means that significant burr removal is less gaining momentum compare to the previous speed that varies from 35 rpm to 55 rpm. This happened is because of the cutting action becoming less due to the motion of the component in the non-effective slide zone and the abrasive media also going to experience more wear as the speed increase [33]. The agitated tumbling barrel causes the solution to circulate and lubricate the media in a smooth

tumbling action which caused burrs are abraded away. Further treatment at higher rotational speed would be linear edge smoothing [34].

#### IV. CONCLUSION

In this study, pre-polishing of the machined CoCr alloys have been carried out using the tumbling process. The rotational speed and tumbling time had been set at certain values in order to investigate their effects on the surface roughness and edge radius. This research found that it is important to know how the parameters of rotational speed and time took determines the motion behavior of elements in the tumbling barrel to supply the collision for the desired purpose of tumbling machining. Relating to the mix of the parameters, it is concluded that the high reduction in surface roughness, Ra of up to 32%, can be achieved at the intermediate level of rotational speed which is 55 rpm in 6 hours of tumbling process. Prolonging the time cycle and speed beyond this point lead progressively to a small difference to the value of surface roughness and degradation of the finish. Much burr removal can be achieved by the higher speed and longer time taken for tumbling process which is 75 rpm within 8 hours. There is a substantial need to reduce, prevent and eliminate burrs so that the part is more likely to be handled safely, assembled, or function effectively.

#### ACKNOWLEDGMENT

The authors wish to place their sincere thanks for financial and technical support to the Department of Mechanical Engineering, Universitas Andalas (project fund with contract number 017/UN.16.09.D/PL/2018), Department of Material, Manufacturing, and Industry of Faculty of Mechanical Engineering at Universiti Teknologi Malaysia (UTM) under a grant (FRGS, No. FRGS/1/2015/TK03/UTM/01/3). The authors also wish to acknowledge the Department of Mechanical Engineering, Faculty of Engineering, Universitas Negeri Padang, and all the staffs involved for valuable support provided during this work.

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