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Influence of acid chemical treatment on the tensile properties of halloysite nanotubes reinforced thermoplastic polyurethane composite

Tayser Sumer Gaaz[1,3]*, Abu Bakar Sulong[1], Abdul Amir H. kadhum[2]

[1)]Department of Mechanical & Materials Engineering, Faculty of Engineering & Built Environment, University Kebangsaan Malaysia.
[2)]Department of Chemical & Process Engineering, Faculty of Engineering & Built Environment, Universiti Kebangsaan Malaysia.
[3)]Department of Equipment's & Machines Engineering, Technical College Al-Musaib, Al-Furat Al-Awsat Technical University, Iraq.

*Corresponding e-mail: taysersumer@gmail.com
Keywords: Polymer composites; Nanofiller; Chemical treatment; Mechanical properties.

ABSTRACT – In this study, the effect of adding halloysite nanotubes (HNTs) at low weight amounts of 1, 2, and 3% to thermoplastic polyurethane (TPU) and, secondly, to examine the effect of acid treatment of TPU-HNTs composites on the mechanical properties. The samples were fabricated using injection moulding. The composites were characterized according to their tensile properties including tensile strength, tensile strain, and Young modulus. The loading has shown the highest mechanical values at 2 wt.% HNT loading and same findings are shown with the samples that treated with acid. The tensile strength increases to 23.78 MPa compared with untreated of 22.14 MPa showing an improvement of 6%. Regarding the tensile strain, the improvement was about 8% at 2 wt.% HNT loading. For Young modulus, the results obtained in this study have shown that Young modulus is linearly improved with either the loading content or the acid treatment achieving its highest values at 3 wt.% HNT of 13.3 MPa and 15.2 MPa for the untreated and treated samples respectively.

1. INTRODUCTION

Thermoplastic polyurethane (TPU) is mainly used in a wide variety of applications such as automotive, screens, roller systems and films, etc. [1]. Thermal stability, fire redundancy, mechanical properties like gas barrier properties, and other properties could be improved in polymer composites [2]. Over recent decades, many polymer composites have been prepared and combined with various types of synthetic reinforcing fillers, in order to improve their mechanical properties and obtain those characteristics demanded by actual applications [3]. Halloysite nanotube (HNT) is a compound that consists mainly of aluminosilicate nanoclay mineral with natural nanotubular structure [4-6]. Generally, HNT is used widely in a range of applications in numerous areas used in thermoplastic, plastic, polymer and other composites as additive fillers. Its hollow nanotubular structure has made it a potential substance for use in the production of biomedical applications [7]. As a nanoclay mineral, halloysite is used in the production of high quality porcelain products [8]. The aim of this research is to investigate the effect of acid chemical treatment on TPU-HNTs composites.

2. EXPERIMENTAL

2.1. Materials

TPU from Global Innovations-polycarbonates Bayer material science AG, D-51368 Leverkusen was used while HNT was purchased from Natural Nano, Inc., 832 Emerson Street Rochester, New York.

2.2. Preparation of composite

TPU and HNT were dried in a vacuum oven at a temperature of 80°C for 12 hour. TPU-HNT composite was homogenized using a Brabender mixer (Model W 50 EHT) Corder PL 2000 compounder equipped by a 50 cm^3 kneader chamber. The matrix was mixed in the mixer until stabilization of torque, and then filler was added into the mixer. After mixing the composite using the Brabender mixer, the samples were injected and TPU-HNTs composites samples were fabricated at different HNT loading percentages for study the tensile properties.

2.3. Testing Equipment

Tensile properties were measured using an Instron 5567 machine, according to ASTM D-638 type V [1]. Five specimens were tested with a crosshead speed of 50 mm/min [1].

3. RESULTS AND DISCUSSION

3.1. Effect of loading HNT on the tensile properties of TPU-HNT composite

Figure 1 shows the results of the tensile strength, the tensile strain, and Young modulus of TPU-untreated HNT at 0, 1, 2 and 3 wt.% HNT and TPU-treated HNT of 0, 1, 2 and 3 wt.% HNT. The tensile strength of 0, 1, 2 and 3 wt.% untreated HNT are 17.7, 19.48, 22.14, and 18.18 MPa respectively as shown in Figure 1 (a). In the same figure, the tensile strength of TPU-treated HNT of 0, 1, 2 and 3 wt.% HNT are presented at 17.7, 20.91, 23.78, and 19.75 MPa. The treated and untreated HNT show no influence of the acid since the tensile strength was found to be at 17.7 MPa as shown in Figure 1 (a). The results showed that the highest tensile strength value obtained was at 2 wt.% HNT untreated or treated (22.14 MPa and 23.78 MPa, respectively). Seemingly, the HNT-acid treatment has improved the tensile strength by about 7%. The interaction between the matrix and the HNT reinforcement composites was the best due to the good dispersion between the layered silicate of HNT and the TPU chains as mentioned before

[2]. The finding suggests that improving the bond strength results in the highest tensile strength. At the highest treatment of 3 wt.%, the tensile strength of the untreated and treated declined compared to the 2 wt.% samples from 22.14 to 18.18 MPa and from 23.78 to 19.75 MPa, respectively. At higher loading above TPU-3 wt.% HNT, the tensile strength decreases which could be attributed to the agglomeration of the HNT nanotubes which naturally leads to poor interaction between the matrix and the HNT. For untreated and treated HNT samples, there is no difference which means that the acid has no effect on HNT in this regard. Similarly to the tensile strength, the tensile strain of untreated and treated has its highest values at 2 wt.% samples has shown improvement by 720.8 and 784.9%, respectively as shown in Figure 1 (b). These results show that the tensile strain has improved by about 9% which is very close to the improvement of the tensile strength. The Young modulus results for the same sequence are shown in Figure 1 (c). Firstly, the results show that Young modulus of the untreated samples increases linearly with wt.% HNT loading achieving the highest Young modulus at 13.3 MPa while the Young modulus of the treated samples was recorded at 15.2 MPa at the 3 wt.% HNT loading. Secondly, the Young modulus of HNT treated or untreated showed no difference.

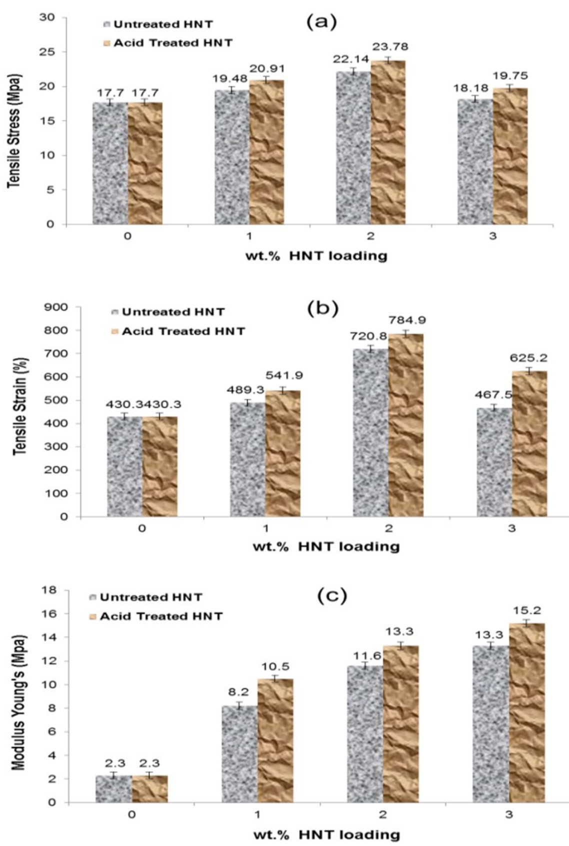

Figure 1 Effect acid treated of HNT on the tensile properties of TPU-HNT composites. (a) Tensile strength, (b) Tensile strain, and (c) Modulus young's

4. CONCLUSIONS

TPU-HNT composites of high modulus and strength were prepared and tested. The composites showed improving the mechanical properties when loaded with HNT and treated with acid. These composites, with filler loading, provide traditional composite properties with all of the advantages of composites. The HNT, as filler, has shown impact on the mechanical properties by improving the tensile strength, the tensile strain, and Young modulus by 7-9%. TPU-HNT composites, with the enhanced properties of TPU were achieved at HNT loadings of 2 wt.%.

ACKNOWLEDGEMENTS

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Study on Dental Restoration Feasibility Using Time Compression Approaches

Nurul Hatiqah Harun[1], Mohd Shahir Kasim[1], Hambali Boejang[2], Hassan Attan[2]*, Raja Izamshah Raja Abdullah[1], Hema Nathini Ganesan[1]

[1)] Faculty of Manufacturing Engineering,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya,
76100 Durian Tunggal, Melaka Malaysia
[2)] Faculty of Engineering Technology,
Kampus Teknologi, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya,
76100 Durian Tunggal, Melaka Malaysia

*Corresponding e-mail: hassan@utem.edu.my
Keywords: Rapid prototyping, reverse engineering, dentistry

ABSTRACT –Time compression technologies (TCT) is one of concurrent engineering approaches during product and process development. TCT uses reverse engineering (RE) and rapid prototyping (RP) techniques that widely used in dentistry and medical sector. Taking advantages of new technology in CAD software, rapid mechanical prototyping possible to fabricate complex-shaped three-dimensional (3D) in a short time by using RP machine. The current practice of dental restoration process in dental laboratory is time-consuming. Therefore, this paper presents the possibility of TCT approach can be applied as to replace conventional process in producing dental crown. The TCT approach has been applied and compared to conventional approach throughout this experiment. Even though, the process of TCT is faster and simpler than the conventional process. The result shows that crowning process difficult to be fabricated as desired. The problem arises due to the limitation of fused deposition modelling (FDM) machine that cannot build the part with the thin thickness of 300 μm.

1. INTRODUCTION

TCT is extensively used as a tool in concurrent product and process development. One of the applications of the TCT notified in RE and RP is in the field of dentistry and medical sector. Rapid mechanical prototyping enables to fabricate complex-shaped 3D immediately from computer aided design model (CAD) [1]. Currently, the process of dental restoration in the dental laboratory was done manually and time-consuming. Therefore, this paper reports on the assessment of possibility this modern TCT approach can be applied during dental crown fabrication.

2. METHODOLOGY

For pre-processing, the sample of impression was taken from the patients to be cast by using dental stone which then mixed with water. The slurry of the mixture then slowly poured into the vibrating assisted impression mould to avoid trapped bubble. Then, the cast is left for curing for 30 min. The hardened plaster model of teeth then was scanned by using RE brand Faro, Model Faro Arm, serial number P08-05-08-41000. This non-contact digitizing method was selected because of the faster digitizing image with 10000 points/sec method than contact approach method [2]. The image digitized data in a point cloud form then manipulated by using Geomagic Studio 2013. Geomagic Studio is used to repair defect point cloud data of the digitized image. After that, this data has been exported to MagicRP version 17.02 for the final design. The teeth had been set with a hollow thickness of 300 μm to mimic actual crown dimension. The RP machine brand Projet 3500HD is being used to fabricate the dental crown. The machining accuracy is between 25-5 μm. Finally, the crown underwent a de-waxing process to remove the supporting wax around the crown. The process took 15 minutes with the temperature of 70ºC inside the oven.

3. RESULTS AND DISCUSSION

Figure 1 shows the crown after being fabricated by using RP machine. It was notified that the remaining wax stuck on the part surface. Meanwhile, Figure 2 shows the result of the crown after de-waxing.

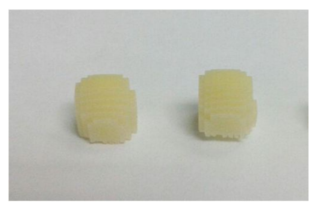
Figure 1 The crown after being fabricated

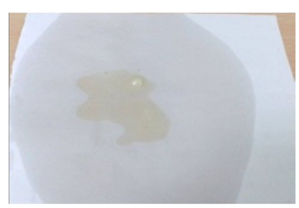
Figure 2 Crown after de-waxing

The result shows that the crown completely melts after this process which changed the designed dimension. There are three factors that might be the causes of defect:

i. Machine Limitation - The machine to fabricate crown has the accuracy of 25-50 μm, whereas, the thickness of the crown is only 300 μm. It shows that the crown failed to be fabricated well enough due to machine limitation. The error could be due to build parameter, part geometry, size, part orientation and post processing.

ii. Thin Wall Issues - The thickness of the crown is only 300 µm. The wall is too thin to be fabricated by using FDM machine. Based on the previous study by Boejang et. al. [3], the FDM machine is said to be inaccurate during forming of circular part. Besides, dimension less than 2000 µm causes the dimensional error of 127 µm. The recommendation by FDM manufacturer also suggested 0.4 mm minimum wall thickness to be fabricated [4].

iii. Parameter for Fabrication - Part of orientation is the parameter to be considered for fabrication. To confirm the effect of this parameter, it was tested with a different orientation. The hollow crown with minimal thickness of 300 µm had been fabricated with up facing and horizontal orientation. From the result, it shows that the part orientation does not affect the result. Based on the failure crown result in the initial fabrication, the process has been redesign where the hollow part was changed into solid. However, the bore of crown needs to be ground manually. The problem arose was the difficulty to fit with a model during fit and form test. The grinding process of crowning is a problematic process because of the size of the small part.

Finally, the dental crowns of conventional processes against modern approach can be compared in term of process flow and build time. Table 1 shows the build time comparison between conventional processes against the modern approach. In the conventional process, the total time taken required to produce one complete metal crown is 40 hours for 5 working days. Meanwhile, the build time required by the modern approach is 19 hours and 50 minutes. It shows that the total time taken have been reduced to 52.5% by using modern approach.

Table 1 Build Time

Conventional Process	Modern Approach
1 week: 5 days x 8 hours : 40 hours	Pre-Processing: 30 min Reverse Engineering (RE) : 1 day x 5 hours: 5 hours Data Manipulation : 5 days x 5 hours: 10 hours Rapid Prototyping (RP) : 1 day x 3 hours: 3 hours Post Processing: 35 min
Total: 40 hours	**Total**: 18 hours 50 min

Table 2 shows the process flow of conventional processes against the modern approach. There are 22 steps involved in the conventional process. Meanwhile, there are only 6 steps involved in the modern approach. Therefore, it can be concluded that dental crown fabrication process in the modern approach is simpler and shorter compare than the conventional process.

Table 2 Process Flow

Conventional Process	Modern Approach
1. Impression Cleaning	1. Impression
2. Position the Impression	2. Plaster Model
3. Preparing the Mould	3. Scanned the Plaster Model
4. Base Plate Preparation	4. Data Manipulation
5. Drilling the Plate	5. Rapid Prototyping
6. Add the Metal Pegs	6. Crown Manufacture
7. Pour the Dental Stone	
8. Make the Opposing Cast in Plaster Model	
9. Remove the Plasticine and the Impression Tray	
10. Top and Bottom View of the Upper Model	
11. Sanding the Upper Model	
12. Separating the Crown Area	
13. Make the Wax Post	
14. Shape the Top of the Post in Wax	
15. Sprue the Wax Post	
16. Pour the Investment Material	
17. Burnout and Casting	
18. Removing the Metal casting	
19. Sandblasting the Metal Casting	
20. Excess Metal Removed from the Casting	
21. Crown Manufacture	
22. Wax Metal Cast	

4. CONCLUSIONS

As a conclusion, it is possible to produce dental crown by using FDM. However, there is a limitation to fabricate with thin wall thickness as some machine unable to produce dental crown thinner than 300 µm. Therefore, it can be concluded that not all FDM machine suitable for precision parts. Further investigation is needed since this technology can be implemented in producing the dental crown with faster and simpler than the conventional process.

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Flank wear and vibration analysis during end milling of AISI P20+Ni

M. T. N. Hidayah [1], M. Rizal [2], Jaharah A. Ghani [1]*, M. Z. Nuawi [1], C. H. C. Haron [1]

[1)] Department of Mechanical and Material Engineering,
Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia,
43600 Bangi, Selangor, Malaysia.
[2)] Department of Mechanical Engineering,
Faculty of Engineering, Syiah Kuala University (UNSYIAH),
23111 Darussalam, Banda Aceh, Indonesia.

*Corresponding e-mail: jaharahaghani@ukm.edu.my
Keywords: Rotating Dynamometer; piezoelectric; vibration signal; milling

ABSTRACT – In this study, the relationship between the flank wear of a carbide cutting tool and the vibration signals under various cutting conditions were investigated during the end milling of AISI P20. The tests were conducted under various combinations of the cutting speed and feed rate. The vibrations due to the flank wear were measured using piezoelectric sensors embedded within an integrated rotating dynamometer. The amplitude of the vibrations increased with increasing flank wear. The experimental results showed that the amplitude of the vibration signals increased due to the progression of the flank wear with an increase in the cutting speed.

1. INTRODUCTION

The condition of the cutting tool is an important factor in metal cutting operations as this can result in much higher costs due to waste components, damage to the machine tool, and unscheduled downtime [1]. In industries, the tool condition monitoring (TCM) system is mainly used to increase the productivity and hence, the competitiveness, by maximizing the tool life, minimising the downtime, reducing scrappage and preventing damage.

Generally, TCM can be classified into two major categories; direct and indirect methods [2-3]. The direct methods of wear prediction, such as visual inspection based on surface textures, are not cost effective and reliable as tool wear monitoring systems. The indirect methods involve the generation of a data acquisition signal during the machining process, which is then analysed to estimate the tool wear. Some researchers [4-6] have studied the effects of tool wear on the cutting forces, vibrations, surface roughness and dimensional accuracy.

This paper investigated the correlation between flank wear and vibration signals using a wireless telemetry system based on inductive coupling as the data transmitter [7]. The transducer element used in the integrated rotating dynamometer was based on a cross beam type of piezoelectric sensor. It was capable of measuring three components of vibration signals. The vibration signals were then analysed using a new statistical-based method called the Integrated Kurtosis-based Algorithm for Z-filter Technique (I-Kaz™), pioneered by [8].

2. METHODOLOGY

In this study, the milling process was conducted in dry cutting conditions using a Spinner VC450 CNC machine. The experimental set up is shown in Fig. 1. This experiment was carried out for the end milling of an AISI P20 steel cutting tool using a single insert coated with tungsten carbide (Kennametal ADKT103504PDERLC) with coating grade KC725M. The cutting conditions are shown in Table 1.

The piezoelectric arrangement for detecting the vibrations in three channels simultaneously is described in Fig. 1. Three pieces of piezoelectric sensors were mounted onto the transducer elements, where the maximum values of strain and stress were obtained to achieve the maximum sensitivity and repeatability of the piezoelectric sensors. ANSYS was used to perform the static analysis of the force sensing element that was subjected to three directions of force. The transducer element was integrated into the rotating dynamometer based on inductive coupling for the detection the tool wear. When the external forces were applied to the transducer elements, the changes in stress and strain occurred on the surface of the material. The piezoelectric converted the stress into voltage, indicating the vibration signals from the force that was exerted.

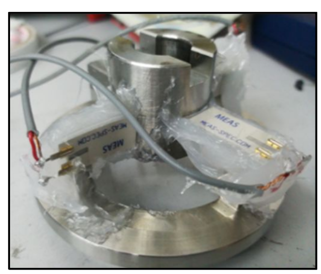

Figure 1 Location of the piezoelectric on the transducer

Table 1 Cutting condition parameters

No. of Exp.	Cutting Speed (m/min)	Feed Rate (mm/tooth)	Axial Depth of Cut (mm)	Radial Depth of Cut (mm)
1	200	0.1	0.4	1
2	300	0.1	0.4	1
3	200	0.2	0.4	1
4	300	0.2	0.4	1

During the milling operation, the insert was periodically removed from the tool holder, and the widths of the flank wear were measured using a microscope. The cutting force signals were collected at a sampling rate of 5 kHz using a wireless telemetry system, and then analysed by the computer using signal analysis based on the I-kaz 3D method, as described by [10].

3. RESULTS AND DISCUSSION

Table 2 shows the resultant vibrations for the series of experiments. Generally, as the cutting speed increased, the resulting amplitude of the vibration signals increased as well. The amplitude of the vibration signals increased with an increase in the flank wear, VB until the criterion of VB = 0.3 mm was met. As the speed increased from 200 to 300 m/min, the resultant amplitude of the vibrations increased from 0.033 V to 0.039 V, respectively at a constant feed rate and depth of cut. Besides that, the increasing feed rate also affected the amplitude of the vibrations when the cutting speed and depth of cut were constant. From Table 2, when the feed rate was increased from 0.1 mm/tooth to 0.2 mm/tooth, the amplitude of the vibrations during cutting also increased due to the progression of the flank wear, which was from 0.033 V to 0.056 V at a constant cutting speed and depth of cut.

Table 2 Results of vibrations from experiments

No. of Exp.	Cutting Speed, V_c (m/min)	Feed Rate, f_z (mm/tooth)	Axial Depth of Cut, DOC (mm)	Resultant Vibration, V_r (V)
1	200	0.1	0.4	0.033
2	300	0.1	0.4	0.039
3	200	0.2	0.4	0.056
4	300	0.2	0.4	0.058

The value of the I-kaz 3D coefficient was influenced by the tool flank wear, as shown in Fig. 2. This was because the larger the resultant flank wear, the higher the value of the I-kaz coefficient for each cutting condition. Besides that, the value of Z^∞ became higher with an increase in the cutting speed or feed rate at a constant depth of cut. The increase in the value of Z^∞ was due to the widening of the contact area between the work piece and the tool. This was similar to what had been stated in previous studies, whereby a larger Z^∞ value indicates a higher degree of data scattering and vice versa [8].

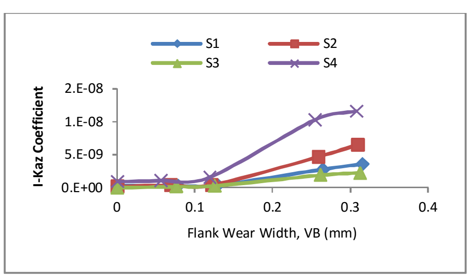

Figure 2 Graph of I-kaz coefficient, Z^∞ against flank wear width

4. CONCLUSIONS

In this study, the relationship between the change in vibration and the tool wear was investigated during the end milling proses. From the experiments, it was proven that the vibration amplitude increased with the progression of tool wear. The effect of the vibrations on the flank wear was more significant in the direction of the main cutting force. The experimental results demonstrated that a wireless system using embedded sensors within the rotating tool in the milling process can efficiently detect changes in the tool wear.

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A Mathematical Modeling of Psychophysical Factor for Driver Fatigue

Mohammad Firdaus Ani [1,2], Seri Rahayu[1,2]* Kalthom Husin[3]

[1)]Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya,
76100 Durian Tunggal, Melaka, Malaysia.
[2)]Department of Manufacturing Management,
Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka,
76100 Durian Tunggal, Melaka, Malaysia.
[3)] Department of Methodology,
Faculty of Education, International Islamic University College, Selangor,
Bandar Seri Putra, 43000 Kajang, Selangor, MALAYSIA

*Corresponding e-mail: seri@utem.edu.my
Keywords: Electromyography; Psychophysical; Mathematical modeling.

ABSTRACT – The purpose of the study is to develop the mathematical modeling of psychophysical factor for drivers' fatigue. Ten subjects participated in this study. The electromyography (EMG) responses were taken and evaluated using Electromyography (EMG) device. The psychophysical factor such as muscle fatigue is one of the contributors to the drivers' fatigue problem, which led to road accidents among Malaysian. To efficiently formulate and develop the mathematical modeling of psychophysical factor, the process modeling using Response Surface Methodology (RSM) was proposed. The aim of this paper is to develop a muscle fatigue model which can predict the relationship between the process input parameters and output response. Design Expert 8.0.6 software was used for the RSM analysis. The mathematical model was successfully developed and validated. The modeling validation runs were within the 90% prediction interval of the developed model and the residual errors compared to the predicted values were less than 10%. The significant parameters that influenced the muscle fatigue were also identified. Muscle fatigue was influenced by the time exposure, type of road, gender, interaction between time exposure and type of road, and interaction between type of road and gender. Throughout this study, the author believes there is a new contribution to the body of knowledge. In future, the author suggest that the more study on developing mathematical model should be focuses as the published RSM modeling work on the application of ergonomics is too lacking.

1. INTRODUCTION

In the modern civilization, transportation becomes an important medium in development of the country. As the developed country, Malaysian nowadays had improvised its transportation, road and highway systems. This improvisation had encouraged infrastructures, facilities and comfort ability among Malaysian users. Obviously, the used of road and highway were Malaysian preferred as this system getting better, cheap and affordable nowadays. As this medium offered huge benefit to human life, it also brings the negative effect on a nation is the loss of life whereby the human factor life is considered priceless. As road accidents in Malaysia always highest compared to other countries in the world, the static being disaster as new killer of the population. Traffic accidents, which involve cars, motorcycles and public transport, become a major problem in Malaysia. Since 1997 until 2014, the statistics shows an increasing number of accidents. According to the Malaysian Institute of Road Safety (MIROS), the rate of road accidents in Malaysia is one of the highest compared to other countries in the world. The road traffic statistic from 1997 to 2014 shows that the total number of accidents had risen from 215,632 cases (1997) to 476,196 cases in 2014. Besides, MIROS has made the prediction on number of fatalities in 2015 and 2020. They predict that there will be 8,760 fatalities in 2015, while 10,716 fatalities in 2020 [1]. Other countries such as United States and France also had record the highest number of traffic accidents. The U.S. National Highway Traffic Safety Administration (NHTSA) reported that every year, around 100,000 traffic accidents and 71,000 injuries related to driver drowsiness, out of which more than 1,300 are fatal. NHTSA estimates that between 2% and 23% of all vehicle crashes can be attributed to driver fatigue [2]. Besides, the National Police Administration of France concludes that 20.6% of accidents causing death are fatigue related [3]. Hence, the drivers' fatigue can be summarized as the one of the leading causes of traffic accidents. Driver fatigue is a significant contributing factor to numerous traffic crashes. Driver fatigue is a subject that is getting increasing attention in the road safety field. Fatigue, sleepiness or drowsiness can be defined as the transitory period between being awake and sleep [4].

2. METHODOLOGY

Subjects and Population

In this study, ten subjects or drivers (five males and five females) which, at least two years driving experiences involved in this study. This ten subjects represented three populations of each gender; big, average, and small. However, only average population of each gender is been discussed in this paper. All the subjects are normal, have healthy bodies and has been told that they are refrained from taking or drinking coffee, tea or alcohol, smoking and free taking any medicine. Before the experiment, the health evaluation has been done 24 hours as to ensure they have enough habitual amount of sleep at night in order to avoid sleep deprivation [5].

Test Apparatus and Protocol

Proton Saga FLX 1.3L engine with automatic transmission was used as the test vehicle. Proton Saga is a national car, also known as national symbol of Malaysia and majority of Malaysian population used it as it is an affordable cars or an economic cars. In monitoring and measuring the muscle activity and overall performance of muscle, the electromyography (EMG) was used in this study. EMG is used to ensure the muscle responsiveness with the electrodes for about 30 minutes. There are four types of muscle where the EMG has been placed as shown in Figure 1; left upper trapezius, right upper trapezius, right biceps and left biceps [6].

RSM Data Analysis

In developing and formulating mathematical modeling, RSM data analysis was carried out through this study. As discussed in early section, RSM is the suitable and the application of RSM in modeling and optimization has been proven in various fields. According to Montgomery (2008) RSM includes a collection of mathematical and statistical techniques that can be used for modeling and optimizing of processes [12]. RSM also interpret the relationships between one or more output responses with the significant input factors. The RSM data analysis is carried out using Design Expert 8.0.6 software.

3. RESULTS AND DISCUSSION

EMG functions as measurement of muscle activation in workspace related tasks during the driving session. Through this study, psychophysical factor (muscle fatigue), has been proven as a factors lead to driver fatigue among the Malaysian. Hence, this study will developed the mathematical model based on this factor as to solve the driver fatigue problems. This section will discussed the development, formulating and validation of the mathematical modeling through RSM data analysis.

Thirty-two (32) experimental runs were carried out. The muscle fatigue or the sEMG signal amplitude (voltage) of the subjects while driving for each experimental run was analyzed using an EMG tool. In this experiment, three factors and one response were studied; time exposure, type of road, and gender; whilst muscle fatigue as the response in this experiment. This study used the historical data as the design type because this study focused on finding the main effect and developed the model relationship between all the factors. Sum of squares sequential model (SMSS) and lack of fit test were carried out to determine the appropriate polynomial equations to shows the relationships between the input parameters (factors) and output response (muscle fatigue). These two analyses suggested the relationship between factors and response can be modeled using 2FI (factor of interaction). In this case time exposure, type of road, gender, interaction between time exposure and type of road, and interaction between type of road and gender are the significant influencing factors of the resultant muscle fatigue. From the surface response modeling the 2FI polynomial equation developed to relate the input parameters to the muscle fatigue is shown below:

$$\text{Muscle Fatigue } (\mu V) = 411.66 + 72.31 * A - 283.53 * B[1] + 305.60 * B[2] - 75.36 * B[3] + 146.99 * C - 20.07 * AB[1] + 8.70 * AB[2] + 53.11 * AB[3] + 0.40 * AC - 107.22 * B[1]C + 131.48 * B[2]C - 21.80 * B[3]C + 17.00 * AB[1]C - 31.44 * AB[2]C + 19.94 * AB[3]C$$

4. CONCLUSIONS AND FUTURE WORK

Throughout this study, the RSM can be used to developed mathematical model of psychophysical factor in order to solve fatigue's problems among Malaysian. The mathematical model in the form of polynomial equation was successfully developed to relate the relationship between muscle fatigue input process parameters (time exposure, type of road, and gender) and one output response (muscle fatigue). The model validation founds that the muscle fatigue output of the modeling validation run was within the 90% prediction intervals of the developed model and the residual error which compared to the predicted values, was less than 10%. The research identified the significant parameters that affected the muscle fatigue through ANOVA analysis during the development of the model. Muscle fatigue was influenced by the time exposure, type of road, gender, the interaction between time exposure and type or road, and the interaction between the type of road and gender.

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A study on musculoskeletal disorders among manual materials handlers at construction sites

Baba Md Deros[1*], Mohd Shafie Osman[2]
[1]Department of Mechanical and Material Engineering,
Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia,
43600 Bangi, Selangor, Malaysia.
[2]Politeknik Merlimau, Jalan Jasin, 77300 Merlimau, Melaka

[*]Corresponding e-mail: hjbaba@ukm.edu.my
Keywords: *manual materials handling; musculoskeletal disorders, construction sites, ergonomics*.

ABSTRACT – Safety and health issues have been the prominent cause of accidents and injuries that occur on construction sites. The literature review showed that supervisors and workers lack exposure and knowledge in safety, health, and ergonomic aspects to causes them to neglect safety measures while performing their daily tasks. Other factors cited causing a high risk of accidents at construction sites were due to lack of training, low academic level, inexperience workers, inadequate equipment and lack of safety enforcement. The three main objectives of this study are: to identify the level of MMH workers' ergonomic awareness; to identify employees' body parts that are experiencing musculoskeletal disorders (MSDs) symptoms; and to investigate the MSDs risk exposure level. The five research methodologies employed in this study surveyed questionnaire, body parts symptoms survey (BPSS), Rapid Upper Limb Assessment (RULA), and face-to-face interviews with construction site supervisors and MMH workers medical records. Eighty-two percent (82%) of the MMH workers surveyed in this study felt they did not have adequate safety and health knowledge. In addition, their perception of the workstation, awareness on comfortable and mobility in the work area, surrounding environmental factors such as temperature, lighting and noise were at moderate level scores between 3.23 and 3.67. Meanwhile, their perception with respect to commitment and attitude towards ergonomics application, safety, and health, correct execution of MMH activities were higher than moderate level score ranging between 4.05 and 4.19. BPSS results showed a high number of MMH workers were experiencing low back pain (LBP) problems as results of using incorrect method while performing MMH activities in the construction site. RULA result showed a majority of MMH activities obtained a mean score of 7, on arm and wrist positioning, neck, body posture and leg, which shows high risk in term of MSDs problems and action for improvement is done as soon as possible. Face-to-face interviews showed 40% of accidents recorded at their construction sites were due to performing MMH activities incorrectly and exposure to dangerous worksite surrounding. Panel clinics' medical records data showed that low back pain (LBP) contributes 55% and the balance 45% of the MSDs problems faced by the MMH workers in the construction industry were related to shoulder, upper back, knee, lower back, calf, and ankle pain.

1. INTRODUCTION

Manual material handling (MMH) are work activities performed by the worker while lifting, lowering, carrying, pushing and pulling the load manually using their hands. In the construction industry, MMH activities are cheaper compared to using conventional machinery and it is more flexible, which makes it a popular choice. However, repeated and continuous MMH activities, awkward positions, incorrect methods employed and high amount of loads could cause serious MSDs, especially; low back pain (LBP) problems [1]. Incorrect MMH activities could potentially cause inflammation on the nerves and human muscles [2]. MMH activities that involve crouching and hip twisting may also cause MSDs problems, which resulted in the loss of control over motion, stability and body support through muscles and ligaments [3]. Construction workers works with physical risks such as over load, awkward posture, and repeated motions. This makes the workers felt uncomfortable, which leads to early symptoms of LBP, such as discomfort in the hip area. If there is no improvement measures were taken, the back pain will become aggravated and more frequent. This research looks at the relationship between ergonomics principles and MMH practiced by the construction workers. Correct MMH implementation is vital to ensure workers safety and health as well as minimizing the risk of MSDs and LBP.

2. METHODOLOGY

This research had utilized the survey instrument to collect the required data. The survey forms were distributed to the MMH workers at the three construction sites. A pilot study was conducted on 12 MMH workers, which showed the questionnaire has an Alpha Cronbach (α) reliability value at 0.852. The five research methodologies employed in the study surveyed questionnaire, body parts symptoms survey (BPSS), Rapid Upper Limb Assessment (RULA), and face-to-face interview with construction site supervisors and MMH workers' medical records. Later the collected survey data was analyzed by using SPSS, Version 20 to determine the frequency, percentage and mean score with respect to MMH workers' safety and health awareness at the workplace. The BPSS was used to identify the MMH workers that are facing MSDs problems such as low back pain (LBP) at their respective body parts. Meanwhile, RULA postural analysis method was carried out to analyses the MMH work method and workers who have the MSDs problems to determine and later to recommend the appropriate type and level of actions that needs to be taken.

3. RESULTS AND DISCUSSION

Worker's awareness on ergonomic and MMH

Based on the survey result, 82% of the MMH workers agreed that they did not have adequate ergonomics knowledge. The mean scores for MMH workers' perception on their: workstation at 3.4; awareness on comfortable work area at 3.23; and mobility in the work area at 3.33 were all at a moderate level. In addition, data analysis showed MMH workers have moderate perception level towards environmental factors, such as temperature and lighting aspects with the overall mean score at 3.56 and noise perception level at 3.67. The noise had a direct effect on the MMH workers. Overall, the ergonomic awareness towards the environment is at a moderate level with a mean score of 3.56 for all surrounding aspects that includes ventilation, comfort, lighting and noise.

Analysis on the MMH workers' perception of their commitment and attitude towards ergonomic application was found to be at higher than moderate level with an overall mean score of 4.05 and towards safety and health indicates a high awareness with a mean score of 4.19. The perception on the correct execution of the right method for MMH activities with a mean score at 4.19. This is directly related to the MMH workers' knowledge in ergonomics, such as attending the ergonomic seminar, the negative consequence of neglecting ergonomics and MMH activities.

Body Parts Symptoms Survey (BPSS)

BPSS was conducted to investigate their current practice with respect to performing MMH activities. MMH workers are required to indicate their level of discomfort on their body parts by choosing one of these five answers: very comfortable, comfortable, neutral, uncomfortable and very uncomfortable. BPSS results showed a high majority of MMH workers are experiencing low back pain (LBP) problems, which due to the incorrect MMH method used while performing MMH activities in the construction site.

Rapid Upper Limb Assessment (RULA)

The procedure carried out RULA assessment was by observing the MMH workers body motions while they are performing their MMH activities, such as lifting, lowering, carrying, pushing and holding the load up to 50 kg.

RULA result showed a majority of MMH activities obtained a mean score of 7. For arm and wrist, the range assessment score were 5 to 7, which indicates high risk on both arm and wrist positioning. For neck, body posture and leg majority of the MMH workers obtained scores between 5 to 10, which shows high risk with respect to MSDs problems. The combination of upper and lower muscles as well as the work posture had indicated that the MMH activities performed achieved the score of 7. This means the MMH activities is required to be further investigated and action for improvement is done as soon as possible.

Interview with construction site supervisors and MMH workers medical records

Based on the information obtained from face-to-face interviews with the construction site supervisors, 40% of accidents recorded at their work sites were due to performing MMH activities incorrectly and exposure to dangerous worksite surrounding. Meanwhile, panel clinics' medical records data showed 55% of musculoskeletal disorders (MSDs) problems faced by the MMH workers in the construction industry is a low back pain (LBP). The other 45% of MSDs problems are related to shoulder, upper back, knee, lower back, calf, and ankle pain.

4. CONCLUSIONS

The MMH workers' ergonomic awareness towards MMH activities is at a moderate level. The management needs to take the responsibility for improving the MMH workers awareness level. This is vital to ensure they are practicing the correct method, while performing MMH activities, thus able to lower the MSDs problems, such as LBP among their MMH workers. The BPSS results showed 10 MMH workers were found to suffer from LBP and other MSDs symptoms. RULA observation and assessment results showed the MMH activities performed achieved a score of 7. This means that the current MMH activities need to be further investigated and changes were to be implemented as soon as possible. Should this left unattended, the LBP and other MSDs problem would become more serious and dangerous to the MMH workers. The results found in this study is in-line with finding by Azhar [4] who found if the MMH workers understanding on the right MMH technique is sufficient, their safety and health would be in good condition while the work productivity would increase.

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Disruption Recovery for a Single Stage Production-Inventory System with Optimal Safety Stock

Mohamad Faisal Mohamad Sobri [1], Hawa Hishamuddin [1*] and Noraida Azura Md Darom [1]
[1]Department of Mechanical and Materials Engineering, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia
*Corresponding e-mail: hawa7@ukm.edu.my

Keywords: *Supply disruption, recovery model, safety stock, production-inventory system*

ABSTRACT – Supply chain management practices are aimed at creating an ideal system for the flow of information, materials and finance. More often than not, the production and procurement decisions that have been made are prone to disturbances that hinder them to be executed as planned. This paper analyzes the recovery model of a single stage production-inventory system with disruption to the production. The proposed model uses safety stock as a mitigation strategy to reduce the impact of disruption to the original schedule. LINGO software was used to analyze the developed model in order to obtain the optimal recovery schedule that minimizes overall system costs. The results show that the total cost is highly dependant on the length of disruption period. For long periods of disruption, the manufacturer will require bigger safety stocks to satisfy the demand and achieve recovery with minimal costs. The proposed model could be a useful tool to assist the manufacturer to generate an optimal recovery plan for post-disruption contingency action, and integrating mitigation strategy by keeping optimal levels of safety stock.

1. INTRODUCTION

The supply chain is a system that involves organization, technology, activity, information, and resources in the process to deliver products from the supplier to customers. The activities in a typical supply chain involve the process to transform the raw material into the finished product before delivery to the end customers [1]. In the ideal supply chain system, all processes will run as planned and per schedule. However, in reality, there will be uncertainty that can disrupt the system. Extreme disruptions could badly disrupt the major operational activities of supply chains [2]. As the impact of disruption to a supply chain can be damaging, firms struggle to take appropriate measures in order to quickly recover from a disruption. Thus, a vital aspect of supply chain disruption management is the development of decision support systems to aid managers during these critical times [3].

In the previous literature, several works have been done to determine the optimal safety stock during production disturbances. In the works of Ki Ling and Warren, the mitigation method to face disruption in the form of machine breakdown is by conducting preventive maintenance activity [4]. This strategy is usually combined with the use of safety stock in order to achieve an optimal balance between inventory cost and maintenance cost. Another similar work developed an optimal algorithm to calculate preventive maintenance schedule and safety stock that minimizes cost per unit time [5]. Louly and Dolgui presented a model for multi-component inventory control at single level [6]. This research developed an approach for calculating the safety stocks for single-level assembly components with unreliable delivery time.

The focus of this paper is to seek an optimal recovery schedule for a single stage production-inventory system that owns safety stock, where random supply disruption occurs and affects the production. The mitigation strategy chosen is to use safety stock to avoid any shortages in the system. This paper will compute the optimal safety stock based on production parameters and calculate the optimal recovery plan for schedule recovery. In addition, the model will consider disruption that occurs either at the start or in the middle of a production cycle. The results of this research are aimed to assist manufacturing firms in selecting the most suitable recovery strategy plan for their organization during critical times.

2. METHODOLOGY

This section will present on the development of the mathematical model for a single production-inventory system with disruption. The basis of the model without disruption is the inventory system of lot-for-lot production in [7]. However, in this study, safety stock will be considered in the production inventory system.

The notations used in developing the model are as follows:

A: setup cost for a cycle (\$/setup)
D: demand rate for a product (units/year)
H: annual inventory holding cost (\$/unit/year)
P: production rate (units/year)
Q: production lot size in the original schedule (units)
X_s: quantity for safety stock (unit)
T_d: disruption period
T : production cycle time in normal cycle (Q/D)
u: production down time for a normal cycle (setup time + idle time), ($S_t + \delta$)
X_i: production quantity for cycle i in the recovery window (units)
T_i: production up time for cycle i in the recovery window (X_i/P)
S_t: setup time for a cycle
δ: idle time for a cycle
p : production up time for a normal cycle (Q/P)
q : pre-disruption quantity
f : penalty function for addition of recovery window
n: number of production cycles in the recovery window

For the recovery model with safety stock, the total cost will consist of three main costs; setup cost (TC_1), inventory holding cost (TC_2), and penalty cost (TC_3). The sum of all the cost components above gives the total relevant costs of the recovery plan. Therefore, the mathematical model is formulated as follows:

$$MinTC(X_i, X_s, n) = (A \cdot n) + \frac{H}{2P}\Big[q^2 + 2PT_d(X_s + q) + PX_s q + PX_1 X_s + PX_1 q + \sum_{i=1}^{n} X_i^2 + 2PS_t\big(\sum_{i=1}^{n-1}\big(\sum_{j=1}^{i} X_j + X_s + q - i.Q\big)\big) + 2\sum_{i=1}^{n-1}\Big(X_{i+1}\big(\sum_{j=1}^{i} X_j + X_s + q - i.Q\big)\Big) + 2P(S_t + \delta)X_s\Big] + f(n^2) \quad (1)$$

Subject to the following constraints:

$X_i \geq Q$; for i=2,3…n (2)

$X_1 + S_x + q \leq Q$ (3)

$\sum_{i=1}^{n} X_i = nTD$ (4)

$T_i \leq T - S_t$ (5)

$T_1 + T_0 + T_d + S_t \leq T - u$ (6)

Analysis of the developed mathematical model was conducted to evaluate the response of the model. This analysis would be able to show the model's ability in solving various parameters and changes to the objective function of the model. Among test and analysis conducted were a random experiment on system parameters and sensitivity analysis. The mathematical model presented in this paper was solved for five different test problems. The test problems were generated by arbitrarily changing the cost parameters. In each test problem, the value of n was changed until an optimal value of *TC* was obtained. The parameters for test problems are listed in Table 1. Additionally, a sensitivity analysis was conducted to show the effect of different parameters on the developed model. These values were used in the analysis; P=5x10^6, D=4x10^6, A=200, H = 1.2, St = 0.000057, Td = 0.003, and q = 100.

Table 1 Parameters for Test Problems.

Test No.	A	H	Td	St	q
1	200	1.2	0.003	0.000057	0
2	200	1.2	0.003	0.000057	100
3	400	2.4	0.005	0.000057	100
4	400	1.2	0.005	0.000057	100
5	400	1.2	0.003	0.000057	100

3. RESULTS AND DISCUSSION

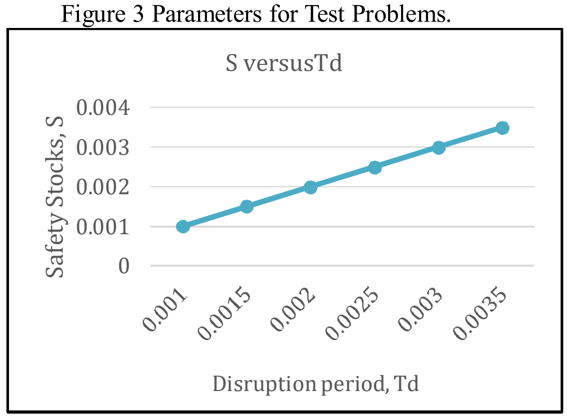
Table 2 shows the value of *n* and optimal *TC* for each test problem. From the table, test problem 1 yielded the lowest *TC* (*TC* = 58408.26). Test problem 2 provided the second lowest value (*TC* = 58528.37) followed by test problem 5 (*TC* = 73069), and test problem 4 (*TC* = 78749.52). The highest value of *TC* was from test problem 3 (*TC* = 120181.40). For test problems 3 and 4, the number of recovery cycles was significantly high due to longer disruption period, *Td*. When *Td* is high, the production quantity in the first recovery cycle X_1 will be small. Thus, the manufacturer will require bigger safety stocks to satisfy the demand at that cycle. Value for *TC1* and *TC3* were highest in test 3 and test 4. The reason for this was due to the dependency of the cost function on the number of cycles. The higher the number of cycles, the higher these costs would be.

Figure 1 shows the effect of disruption period to safety stock. Results show that when disruption period increases, the safety stock also increases. This observation is in line with intuition, as safety stock level needs to be larger in order to support demand and achieve optimal total cost when the length of disruptions are longer.

Table 2 Results for Test Problem.

Test No.	No. of cycle (*n*)	Total cost (*TC*)
1	7	58408.26
2	7	58528.37
3	15	120181.40
4	11	78749.52
5	6	73069.04

Figure 3 Parameters for Test Problems.



4. CONCLUSIONS

A recovery model for a single-stage production inventory system under disruption has been developed, where safety stock was used to reduce the impact of disruption. This model can be used to determine the optimal production quantity and the number of cycles in the recovery window in order to minimize the overall recovery cost of the system.

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