Ergonomics Study of Working Postures in Manual Hand Layup Process

Nur Syafiqah Rayme, Seri Rahayu Kamat, Syamimi Shamsuddin, Wan Hasrulnizzam Wan Mahmood and Noor'ain Azizan

Abstract In composite manufacturing, hand layup is of the fabrication methods that is widely used. Composite is the basic material used in the manufacturing of products such as shipbuilding and the process requires manual handling. Currently, there is a significant number of absenteeism that due to low back pain, indicating that workers in manual composite manufacturing have problems related to musculoskeletal disorder (MSD). The objective of this paper is to study the working posture and discomforts experienced by workers in layup process station. A preliminary survey is conducted on 45 workers to obtain their experience of discomforts while working. Survey results show that 83.33% of the workers experience discomforts on the lower back of the body. When rating their level of pain on the lower back on a scale from 1 (lowest) to 5 (highest), 41% of them rated 4 on the level pain. Pain and discomforts lead to lower productivity of workers. Consequently, this can jeopardise the quality of the products. At the layup station, this problem arises due to the design of current workspace and the posture of workers when executing the job tasks. Rapid Upper Limb Analysis in CATIA V5R20 software was used to calculate the RULA scores. All postures had scored more than 6 that need further investigation and immediate change. Ergonomically designed layup workstations and good education on proper working posture will be able to improve the workers' health conditions on the future.

N. S. Rayme · S. R. Kamat (✉) · S. Shamsuddin · N. Azizan
Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Durian Tunggal, Malaysia
e-mail: seri@utem.edu.my

N. S. Rayme
e-mail: syafiqah.rayme@yahoo.com

S. R. Kamat
Tokushima Malaysia Academic Center (TMAC), Tokushima University, 2-1 Minamihosanjima-cho, Tokushima 770-8506, Japan

W. H. Wan Mahmood
Faculty of Engineering Technology, Universiti Teknikal Malaysia Melaka (UTeM), Durian Tunggal, Malaysia

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1 Introduction

1.1 Ergonomics

Ergonomics is defined by Greek words; "Ergon" which means work and "nomoi" meaning natural laws [7] and is the science of refining the design of products to optimize it for human usage [18]. The word ergonomics are defined in multiple definitions, however, always leads to the similar understanding and improvisation. The academic literature on ergonomics has revealed the emergence of several contrasting definitions. It may, for example, in United States Department of Safety and Health interpreted ergonomics as the study of work [14] thereby draws adaptation in task, workstation, tools and equipment. Such expositions are ensuring that the tasks are fit to a human being because it ease the workloads and providing safer working environment by eliminating risk towards worker's health.

In summary, it has been shown from the reviews that ergonomics, in short, is the study of the interaction between workers, workstation, environment. Ergonomics also is the study of any evaluation and improving methods towards human safety and health. As explained earlier, it does not only focus on the design of the workstation or working tools but also improvising the human towards better working posture by including the mechanics of human.

1.2 Manual Material Handling (MMH)

Manual material handling (MMH) is a working task that requires worker to complete without the help of automation. Example of MMH is lifting heavy products, reaching materials, bending forward their back when doing tasks, pushing or pulling excessive loads because those tasks require a stable position and large degree of freedom [6]. In composite manufacturing especially aerospace manufacturing, most of the work processes were using manual material handling [9]. In contrast with automotive industries and other manufacturing industries, the fabrication or production method are capable to change from MMH to automation. However, some automation in Malaysian manufacturing industries are semi-automated, thus, workers are still prone to be diagnosed with MSD. In MMH stated by Md. Deros et al. [11] is one of the contributors of MSD in workers.

1.3 Musculoskeletal Disorder (MSD)

Musculoskeletal disorder (MSD) is any injuries that caused human movement or musculoskeletal system of a human being become malfunction [12]. The nearest examples are tendons, ligaments, disks, nerves and tissues of a human. This disorder is either caused by working tasks or working environment that related to human safety and health issues.

Some diseases that relate to MSD are well-known to industries and companies. Low back pain (LBP) is one of the diseases related to MSD [13]. Other related MSD diseases are Carpal Tunnel Syndrome (CTS) and Trigger Finger that are caused by ligaments and tendons around the hand area (wrist, palm and fingers). The risk factors for MSD diseases are correlated to Ergonomic Risk Factor (ERF). ERF is the risk factors that are correlated to working tasks where workers are prone to occupational injuries and in Malaysia, manufacturing industries recorded the high number of occupational injuries [5]. Previous researchers have established that the activities that contribute to ERF are excessive lifting, repetitive movements and awkward postures [3, 5, 9, 11, 16].

1.4 Low Back Pain (LBP)

The term LBP is used here to refer to pain related to the lower part of the body. Specifically, it is defined as pain that is located anywhere from the range between the twelfth rib to inferior gluteal folds, with or without leg pain [10] (refer Fig. 1). One possible implication of LBP is that it became the strongest predictor of absenteeism [13]. This is correlated with the interview session with one of the Safety and Health officers of manufacturing sectors that says most absenteeism are claimed by the cause of a backache [20]. Awkward posture is one of the causes of getting LBP [17]. In previous studies, awkward posture is one of the ERF, hence, most manufacturing industries working tasks are categorized as ERF.

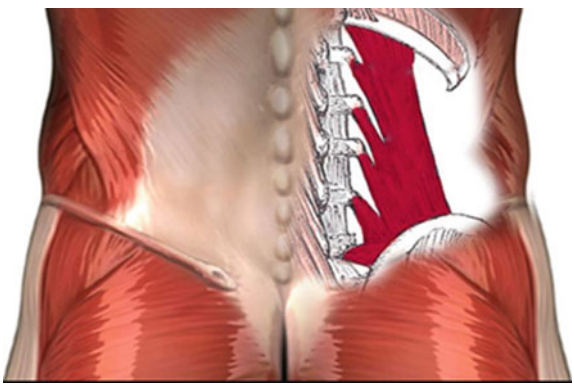


Fig. 1 The figure of 12th rib to inferior gluteal folds. *Source* [15]

1.5 Composite Manufacturing

Composite manufacturing is on demand nowadays because of the composite characteristics. In the same way, the composite is a cost-effective material when it comes to typical weight-sensitive structure such as aircraft and spacecraft [8] similar with the manufacture of ship parts. In composite manufacturing, especially Malaysia, automation is not adaptable because of the difference in production demands as a large initial investment that are required in automated machinery and the price is up to the degree and complexity of the automated machine and with automation machining contributes a higher cost and requires higher intelligent workers.

1.6 Manual Hand Layup

In layup process, it is known as "hand layup" where manually setting down individual layers of carbon reinforcement composite known as "prepreg" for example the close up layup in Fig. 2. It is layered per the mould shape leaving no air between sheets of composites [2]. Hence, knowing the cruciality of a manufacturing process will help in understanding the process flow and then making the ergonomics study become easier. Elkington et al. [2] also, stated that the layup process had been changing for the past 30 years and this somehow provides a room for improvement in the manual process in terms of ergonomics study. This is due to a limited research study that had been done in this layup process flow in Malaysia. Recent studies conducted by Hashim et al. [6], were based on biomechanical factors

Fig. 2 Hand layup up close-up. *Source* [2]

of push-pull analysis at the aerospace manufacturing in layup process department. Their studies show that the layup process department does have ergonomic risk factor in pushing activities because after the mould had been completed by layup, the workers must manually push the mould to the autoclave sections. Another study has been done by Malaysian researcher at layup process department was on the MSD risk of workers and it covers the design of the workstation is suited to the anthropometry of the workers [9].

The aim of this study is to investigate the working postures of the layup process department workers by including the anthropometry measurements of the Malaysian manufacturing workers. This is due to a significant number of absenteeism due to a backache [20]. The manual layup workers are observed in their postures while doing the working task. From critical working postures identified in this study, only three awkward postures are taken as sample. Later the postures are evaluated using the Rapid Upper Limb Analysis (RULA) in the virtual environment of Computer-Aided Three-Dimensional Interactive Application (CATIA) V5 software.

2 Methodology

This study embarks quantitative and qualitative methods in obtaining the data. In the first stage of the research, literature studies were done in order to obtain the methodology for the whole process. Similar from studies done by previous researchers, this study will be using software which is CATIA V5 to prove that the awkward posture of the workers was having high risk in getting MSD as hand layup process which is classified as MMH.

In this study, a survey was developed based on conceptual guidelines proposed by Crawford [1]. This survey was validated by using expert evaluation which is the manufacturing company safety officer and head of the department of safety and academician with ergonomics expertise. The next step will be approaching the software procedures to validate survey data obtained.

Apart from that, in CATIA V5 software, the awkward postures were imitated inside a virtual environment in software. RULA analysis features in the Ergonomics section of the CATIA software was used to evaluate whether the awkward postures were having a high risk of getting MSD. This is the validation of the Survey answers regarding the discomforts experience that felt by the subjects.

2.1 Survey Participants

The participants for survey were selected based on working area. Since the study was researching about manual hand layup, the participants were the workers that are working in the layup department in a composite manufacturing industry. In order to

understand the layup process clearly; interviews, observations and literature methods were adopted in this study.

Nonetheless, the study covers only one department of a layup that is occupied by 45 personnel for two working shifts was selected. In an attempt to make the participants feel as comfortable as possible, the survey was explained one on one participants to ensure the participants understood the purpose of the surveys. For this survey, the session took two weeks to be fully completed.

To begin the process, prior to data collection, the participants received an explanation of the project. After the collection, using one on one interview method, the data was transferred to Microsoft Office Excel 2016 for graphical presentation. Once, the data were extracted from surveys, it was first necessary to plot into graphical in order to observe the trend. Following to this data presented, CATIA V5R20 software with RULA analysis features was used to validate the data from the Survey.

2.2 CATIA V5R20 RULA Analysis

Many researchers have utilized CATIA V5 software to analyze ergonomics issues virtually such as Hashim et al. [6] and Kamat et al. [9]. Traditionally, RULA analysis had been assessed by using RULA assessment sheet that needed an evaluation from ergonomics or RULA experts. However, there are certain drawbacks associated with the use of this method. This is because the expertise needed to require some cost in accessing the RULA. The major advantage of using CATIA V5 software compared to traditional assessment method is that cost-saving and simple. Some of the composite manufacturing is very difficult to access because of confidentiality issues and business purposes, hence, it is complicated to invite outsiders that are considered as ergonomics expert into the manufacturing companies. Hence, the RULA analysis was done in order to recognize the risk of these awkward postures towards the workers' health that can lead to MSD.

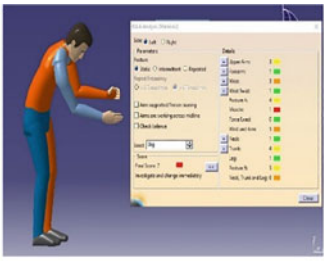
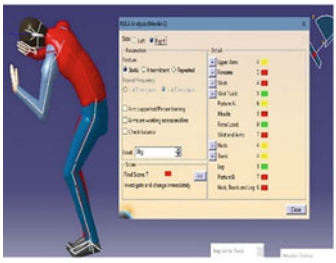
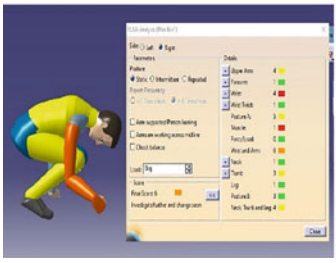
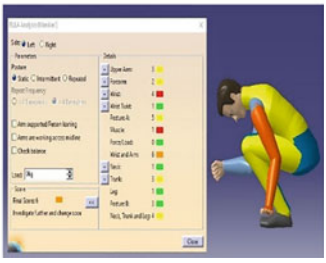
The initial steps of the analysis were to insert the manikin into the environment of the software. In order to do this, the 50th percentile of Japanese manikin population was chosen according to the similar geography of the Malaysian and Japanese, in which located in the Asian region. After that, the postures were imitated in the virtual environment and RULA analysis was done and the score obtained by each posture (as in Fig. 3) were tabulated according to the left and right side of the human body (refers Table 1).

Finally, the correlation between the survey and the RULA analysis score is obtained as the validation of the existence of ERF in the manual hand layup process. In the postural angle, there is a potential bias and human error in the CATIA V5 software, in future, it is recommended that the angle can be detected using Microsoft Kinect camera in order to obtain the correct angles in the human posture.

Score	Level of MSD Risk
1-2	negligible risk, no action required
3-4	low risk, change may be needed
5-6	medium risk, further investigation, change soon
6+	very high risk, implement change now

Fig. 3 Standard score from NIOSH for the comfort level of RULA analysis. *Source* [6]

Table 1 RULA analysis by using CATIA V5R20

Posture	Right	Left	RULA score
1			7
2			7
3			6

3 Results and Discussions

The first set of the questions aimed to identify the percentage of Body Mass Index (BMI) of the overall workers at the current layup department. The second set of questions asked the participants about the body discomforts and the level of pain of body parts whilst working at current layup process. The questions on level of pain are using Borg's scale; where the 1st level indicates no pain and the 5th level indicates the extreme pain.

In this study, the data presented are selected from the survey focusing on MSD that leads to LBP. Hence, this section will cover on BMI, body discomforts and level of pain in the lower back region.

3.1 RULA Analysis and Body Mass Index (BMI)

As described in the methodology section, the RULA score obtained from the CATIA V5R20 software are using the chosen criteria for human manikin in anthropometry measurement sections that are the 50th percentile human manikin and with restriction population of Japanese. As the most obvious finding was that the CATIA V5R20 software available in R20 (a version of release significant to the year 2014) was not competent in providing Malaysian population itself. Hence, the usage of the Japanese population is significant towards Asian countries population based on the geography. However, the current study also found that there were many restrictions in range of measurement that cannot be avoided since the population between both countries had slight differences in terms of BMI especially in obesity class, where 44% of total respondents were obese by referring to Fig. 4 data extracted from the Survey. In Japan, only 3.6% had BMI more than 30 based on Senauer and Gemma [19]. "Malaysia is ranked sixth in the Asia Pacific region for obesity and tops the list in South-East Asia for both obesity and diabetes," stated

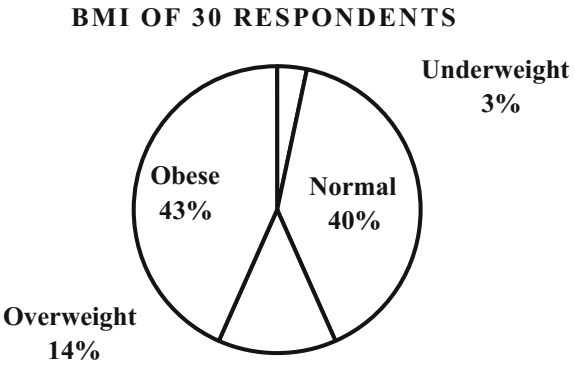


Fig. 4 The BMI of workers from survey

Prof. Dr. Mohd Ismail Noor, the president of Malaysian Society for the Study of Obesity, during a press interview [4]. This proves that there is a limitation in using software analysis in ergonomics features in CATIA V5R20 software.

3.2 Awkward Postures and RULA Score

Several kinds of literature had stated that awkward posture is one of the classified ERF as in Introduction section and RULA score refers to Fig. 3, shows that the maximum score should be 6 and above. This score indicated the level of risk in getting MSD. One interesting finding is that MSD diseases are too broad to discuss as it is related to a human musculoskeletal system where it stated by Morken et al. [13] that LBP is another form of MSD. In Table 1 illustrated three different type of awkward posture that must be applied during the layup process. From the table, it was shown that the first column is the posture type during layup process, and the two-middle column separated left and right coloured human manikin in CATIA V5R20 software with RULA analysis and the last forth column indicated the score for the RULA score for each posture.

Posture 1, 2 and 3 in Table 1 showed the awkward postures while doing the layup process (imitating the real posture). In Posture 1, the worker needed to bend and twist body in order to reach the specific area of the mould composite product. Similar to, Posture 1, Posture 2 was a little bit different in the tool as the tools are used specifically according to the fixed manual obtained from the manufacturing customers. In posture 1, the worker was actually working without a tool (bare hand with gloves) and needed to apply force to layup the ceramic sheets into the mould and Posture 2 showed that the specific tools were used in order to layup ceramic sheet at the edges of the mould.

In Posture 3, however, it represented the most awkward posture between the three where three main body parts were affected due to squatting position, bending of both lower back and neck. This position had to be bear by the worker in order to layup ceramic sheet into that particular part of the mould. Nonetheless, all three awkward body postures of the workers can lead to lower back pain (one of MSD effects on the body) as stated by Roffey et al. [17]. So far, this study had found that all the RULA scores for both left and right posture in Table 1 indicated the score of more than 6 which in need of further investigation as stated by Hashim et al. [6]. However, in one mould of the composite product, the number of resources had been segregated were up to 4 workers per mould. Thus, one worker was not obligated to one type of body posture for the whole 8–12 h of working time per shift.

Although the risk of MSD is low back pain, MSDs can be triggered by other combination of several ergonomic factors from doing the current workload as mention by Roffey et al. [17]. The risk of getting MSD was reflected from the Survey data that had been distributed throughout the session. Finally, the score 7 is related to the discomforts experience that been felt by the respondent whilst working in manual hand layup that had been considered as MMH.

3.3 *Discomfort Experience and Level of Pain*

From the graph in Fig. 5., the workers answered on the discomforts experience on the body is coherent with the RULA analysis by CATIA V5R20 software. Closer inspection of the graph shows that the most answered discomforts body part was the waist, 27 out of 45 respondents answered and second was the lower back where 25 out of 45 respondents had experienced discomforts. This proved the statement by Syed Uda Hashim [20] that sick leaves were caused by back ache since waist and lower back can be classified as back of body. Another significant finding obtained from the process at layup process department was the workload were including the excessive lifting of item that weighed approximately 40 kg into a mould. Apparently, from this study, awkward posture and excessive lifting does have influenced the health of the workers. This is because both working tasks fall into ERF classification [5].

Referring the Fig. 6, the level of pain experienced by the workers at the lower back part of the body is rated by using scale 1–5. The study would like to highlight the level of pain experienced by the workers at lower back body part significant to the aim of this study, in which to find the evidence on the manual hand layup of composite against the LBP. From Fig. 6, 41% of the respondent answered 4 as the level of pain, this is because the pain is still bearable by the workers while doing job according to the workers in Survey session, as after the mould had been filled with ceramic sheets, it needed to be compact (vacuum to remove any air in between sheets) that were done in sequence. Thus, the workers still have time to relief the

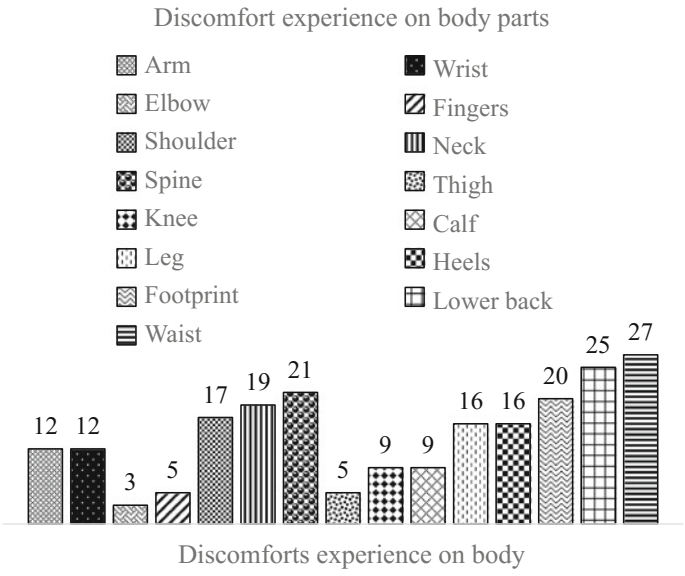


Fig. 5 Discomforts experience on body parts

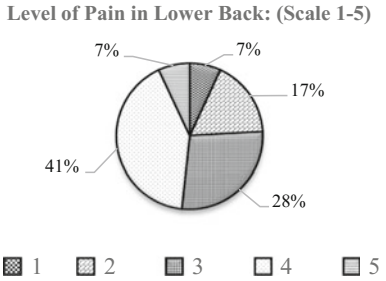


Fig. 6 Level of pain on lower back part of body

muscle pain on lower back before started working on the next sequence in the Standard of Procedure (SOP). However, from the study, the significant finding was similar to Hashim et al. [6] where it was deducted that the lower back pain is associated with bending forward back in a long period of time and static contraction of muscles on the back part of the body.

4 Conclusion

In shorts, the current study aimed to investigate the working postures of manual hand layup process. This study had shown that manual hand layup process had a significant impact on the human health. Overall, this study strengthens the idea of manual hand layup does have ergonomic risk. The study confirms that there is a need for ergonomics study in composite manufacturing, this is because one the fabrication method of the composite is manual hand layup. In order to reduce the risk of getting MSD, this study suggested that the posture of the workers should be change and reanalyse by making sure the score of RULA is reduce from 7 to at least 5.

Being limited to awkward posture, the study lacks in proving caused of LBP thoroughly. Hence, it would be interesting if the study involved any experimentation on participants that includes the usage of surface electromyograph (EMG) as to detect the time to fatigue when doing the layup process. A further study should access the time where muscles on the lower back start to fatigue and in anthropometry section of CATIA V5R20 software, the next study can embark in creating Malaysian population anthropometry database that can be uploaded by Dassault Systemes in the software produced by the company.

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