RADIOGRAPHIC IMAGING OF STEEL OVAL LOCK CARABINER BY USING COMPUTED RADIOGRAPHY: A PILOT STUDY

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ABSTRACT

Introduction: Carabiner is one of Personal Protective Equipment (PPE), which is used to protect the users from hazards by reducing any chance of serious injury. Thus, it is very important to detect even a small defect on the component before it becomes worse that could give harm to the users. The aim of this paper is to find out the appropriate imaging technical factors of steel carabiner by using computed radiography (CR). **Methods**: Radiographic images of carabiner were obtained by manipulating the values of kVp and mAs with respect to contrast and density. A preliminary study was carried out to determine the exposure factor combination in order to produce perceptible visual quality of radiographic images. Positioning techniques applied in this study were whole view (open-gate and close-gate position) and screw view (open-gate and close-gate position). An assessor was invited to evaluate the radiographs by using Image Quality Criteria Scoring (ICS) adapted from European Guidelines on Quality Criteria for Diagnostic Radiographic Images. **Results:** Findings showed that the optimum values of kVp and mAs in imaging whole view (open-gate and close-gate) carabiner were 133 kVp and 28 mAs while, for screw view (open-gate and close-gate) the range of kVp and mAs preferred were 121 kVp to 133 kVp and 28 mAs to 36 mAs respectively. **Conclusion:** This study has found that the use of medical CR to expose metal steel such as carabiner is accepted. By manipulating the imaging parameters, CR can produce a good quality image of carabiner.

KEYWORDS: Carabiner, Personal Protective Equipment, Image Quality, Computed Radiography, Exposure Factor

INTRODUCTION

The use of Personal Protective Equipment (PPE) is very essential in a potentially hazardous working environment and its application is a major way to reduce any chance of serious injuries. It is very important to detect even a small defect on the equipment before it develops a fatigue or stress-corrosion cracks, which could be difficult to detect until it is too late and might lead to catastrophic failure (Georgiou, 2011). Regulatory and non-regulatory standards such as Occupational Safety and Health Administration (OSHA) and American National Standards Institute (ANSI) require that PPE, to be periodically inspected and maintained (U.S. Patent No. 7,464,001B1, 2008). Inspection involves testing, measuring or monitoring certain characteristics of an object or equipment to be compared to specified requirements and standards in order to determine whether the equipment satisfies the target. Visual inspection is one of the most widely used methods of inspection in detecting variety of surface flaws such as corrosion, cracks and discontinuities (Campbell, 2013). Among the factors that influence the choice of inspection methods are costs, type of defects, material composition and the availability of the equipment.

Another method that can be used to detect PPE defects is by using radiography. Any defect that reduces its X-ray absorption will demonstrate a darker area on radiographic image as compared to the other exposed area, where less radiation has reached the image receptor (Anon, 2013). For aluminium and steel castings, electrical parts and a wide range of manufactured components, computed radiography (CR) can be considered as the best method for inspection. Inspection process by using CR makes use of radiation source such as X-rays, cobalt, iridium, or selenium (McDaniels, 2013). Study found that the application of CR in welding inspection has facilitates the detection of weld joints' internal defects and discontinuities (Malik et al., 2013). Another study showed that CR is capable in detecting the discontinuities of joint that contains fluid inside the pipeline (Oliveira, Soares and Lopes, 2011). One of the advantages behind this technique is no line disruption and drainage required prior to the inspection.

It is very important to ensure the safety of PPE before it can be used by the user due to the fact that the key function of the equipment itself is to protect the user from any potentially dangerous environment. If there is presence of any wear damage or any types of deterioration to the PPE, it could endanger the life of the user. Thus, by conducting this study, it is hoped that it can facilitate the inspection procedure of the PPE as a whole by providing a baseline to inspect the metals by using computed radiography.

METHODS

Image Acquisition

Radiographic images were acquired on a Siemens Multix Top General X-ray unit (OPTITOP 150/40/80 X-ray tube with ≥2.5 mm Al/80 kV total filtration). Focal spot capability is 1.0 mm (large focus) and 0.6 mm (small focus). Previous quality control (QC) for the X-ray system conducted by Siemens was taken into consideration to ensure the adequate performance of the X-ray equipment during the conduct of the study. The carabiner used is a new 0981 CAMP steel oval lock, which is made of steel composed of carbon, manganese, nickel, molybdenum, tungsten, chromium and vanadium. Only one carabiner was used throughout the study. For this study, it involved two views of carabiner, which are whole view and screw view. They differed in terms collimation area. Each view comprised of two positions, which are open-gate and close-gate. Overall, there would be four different types of radiographic images (Figure 1).

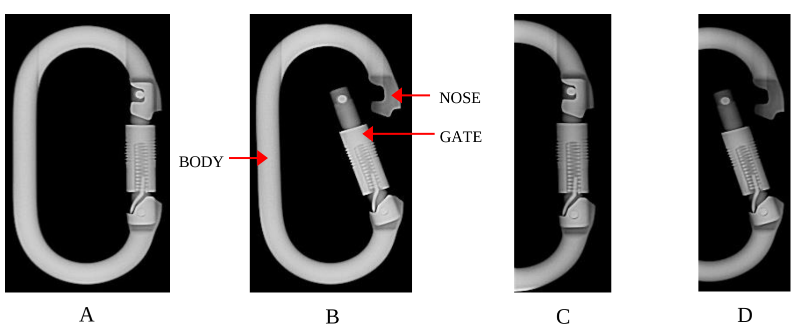

Figure 1 Radiographic images demonstrating different views of carabiner. (A) Whole view (close-gate); (B) Whole view (open-gate); (C) Screw view (close-gate); (D) Screw view (open-gate)

For whole view, it focused more on the body of the carabiner while, screw view clearly showed the components inside the gate. When the gate of carabiner was closed for close-gate position, the nose was superimposed with the gate. In order to demonstrate nose without gate superimposition, the carabiner was exposed with open-gate position.

Images were acquired on the same 18 cm x 24 cm Fuji CR imaging plate without the use of secondary radiation grid. The close-gate carabiner was positioned to direct the central ray to the screw gate, and perpendicular to the imaging plate. The primary X-ray beam was collimated to 1.27 cm (0.5 inches) lateral to the edges of carabiners' body to include the whole carabiner.

In order to evaluate the radiographic image quality, the values of kilovoltage-peak (kVp) and milliampere-second (mAs) were manipulated with respect to contrast and density. A preliminary study was carried out to determine the exposure factor combinations required to produce radiographic images in order to validate the criteria established (Table 1).

Table 1 List of criteria for image evaluation

Number	Criteria
1	Sharp visualisation of body (outer margin)
2	Sharp visualisation of body (inner margin)
3	Sharp visualisation of nose (outer margin)
4	Sharp visualisation of nose (inner margin)
5	Body shows uniform density
6	Sharp visualisation of kick (inside gate)
7	Sharp visualisation of gate (edges)
8	Sharp visualisation of kick (inside gate)
9	Sharp visualisation of gate (edges)
10	Overall image quality

During the study, the kVp was initially fixed at 90 kVp. Images were then obtained at varying mAs values. The first image was acquired with 20 mAs. Subsequent images were obtained by increasing the value of mAs by one increment allowed by the system since there was visible change in image quality perception. At 40 mAs, the investigation was terminated due to the lack of anatomical detail visualisation on the radiographic image. A similar technique was then used to find out the range of kVp. As a result, 20 possible exposure combinations were determined (Table 2).

After finished with the manipulation of kVp and mAs, the whole procedure was repeated with different position, which was open-gate. The experiment then was repeated with another view to only focus the screw gate. In order to obtain this view, the collimation area was set to 1.27 cm (0.5 inches) lateral to the edges of screw gate.

Table 2 List of criteria for image evaluation

Image number	kVp	mAs
1	90	20
2	102	20
3	121	20
4	133	20
5	90	28
6	102	28
7	121	28
8	133	28
9	90	32
10	102	32
11	121	32
12	133	32
13	90	36
14	102	36
15	121	36
16	133	36
17	90	40
18	102	40
19	121	40
20	133	40

Image Evaluation

All radiographic images were evaluated by an assessor who was a welding inspector and currently serves under Malaysian Institute of Non-Destructive Testing (MINDT), with at least five years of experience in industrial field. The assessor evaluated the images by using Image Quality Criteria Scoring (ICS), which was adapted from European Guidelines on Quality Criteria for Diagnostic Radiographic Images with 3-point scale (2=well visible, 1=partly visible, 0=not or hardly visible) for anatomical details of the carabiner. All of the images were evaluated on the same monitor in order to avoid variation between different monitors. The assessor was not allowed to change contrast and brightness features of the software.

Data Analysis

Simple tables and bar charts were used to represent the data on ICS. This method was conducted in order to assess the image quality with respect to contrast and density. For descriptive analysis, data of this study was considered as non-parametric test. This is because the random sampling and normality assumption was not met. This occurs due to the small sampling size for each group, which is less than ten. Furthermore, no sampling method was done since only single subject (carabiner) was used.

RESULTS

Radiographic image quality evaluation in relation to the changes of kVp

Findings showed that 133 kVp radiographs for whole view gives full score, which was 14 for both open-gate and close-gate position (Figure 2). This is because the radiographs have fulfilled all of the criteria required. In contrast, radiographs of 90 kVp and 102 kVp obtained the lowest score for both open-gate and close-gate due to the failing of both radiographs to fulfil the fifth, sixth and seventh criteria for both open-gate and close-gate position (Table 1). Overall, both open-gate and close-gate position show increase in score as the value of tube potential (kVp) increases. It can be postulated that, 133 kVp is a suitable tube potential to be used for both open-gate and close-gate of whole view carabiner.

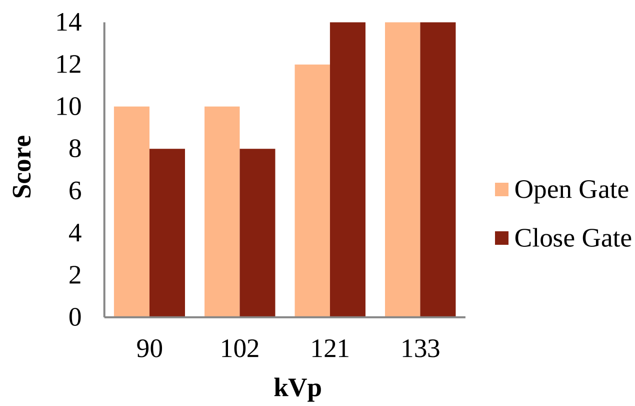

Figure 2 ICS for whole view at different kVp with different position

For screw view, close-gate position obtained full score at two values of tube potential (kVp), which were 121 kVp and 133 kVp (Figure 3) while, no tube potential gives full score for open-gate position since all radiographs fail to fulfil the seventh criterion which was the sharp visualisation of the edges of gate (Table 1). However, the highest score for open-gate position were 121 kVp and 133 kVp, which were similar to the close-gate position. On the other hand, both 90 kVp and 102 kVp give the least score for close-gate and open-gate position. It can be seen that the pattern for screw view is the same with whole view. The score increases as tube potential increases. Thus, it can be assumed that the suitable value of kVp for both close and open-gate position of screw view carabiner is within the range 121 kVp to 133 kVp.

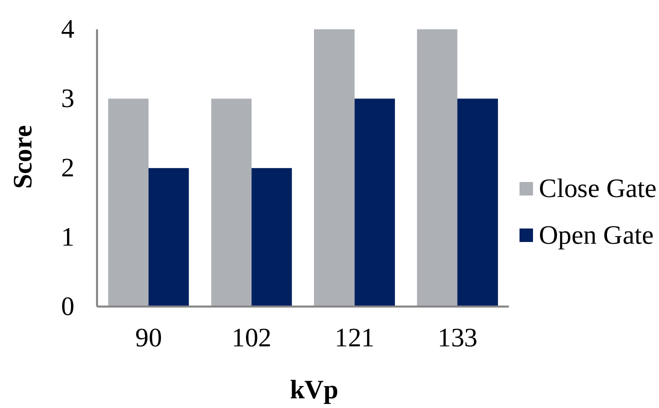

Figure 3 ICS for screw view at different kVp with different position

Radiographic image quality evaluation in relation to the changes of mAs

The best ICS score obtained for whole view was 28 mAs (Figure 4), while the lowest score was 40 mAs. These applied for both close-gate and open-gate position since 40 mAs radiograph failed to fulfil fourth, fifth, and sixth criteria for both open-gate and close-gate position (Table 1). From the assessors' point of view, the radiograph of 40 mAs was an overexposed image while 28 mAs image was considered as optimum. Therefore, it can be deduced that 28 mAs is a suitable milliampere-second to be used for both close-gate and open-gate position of whole view carabiner.

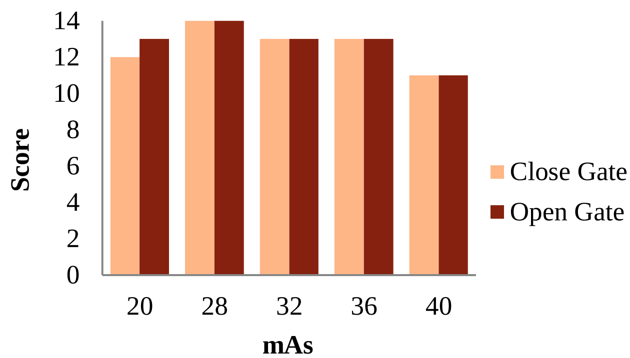

Figure 4 ICS for whole view at different mAs with different position

For screw view, all the images obtained a full score (Figure 5) as all of the criteria required were fulfilled (Table 1). However, from the assessors' comments, radiographs of 20 mAs and 40 mAs were underexposed and overexposed respectively. Hence, it can be postulated that the acceptable range of mAs for both open-gate and close-gate of screw view is from 28 mAs to 36 mAs.

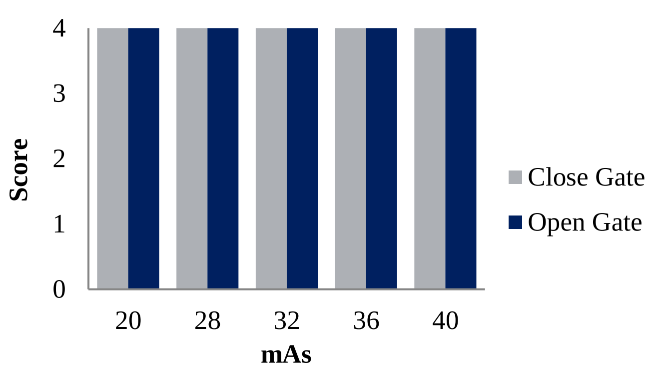

Figure 5 ICS for screw view at different mAs with different position

DISCUSSION

The CR is one of the methods used to inspect the metals (Machado et al, 2011). In imaging metals such as steel, strong penetrating power is crucial to enable adequate penetration of metals with high thickness in order to obtain a good and acceptable radiographic image quality. The key in determining an appropriate penetration is the construction characteristics of the material itself. For material steel, it requires at least minimum 100 kVp to enable the X-ray beam penetration throughout the metal thickness (Raad and Kuiper, 2008).

In this study, 133 kVp images showed excellent image quality as compared to the other selected kVp due to the improvement in X-ray penetration which result in better visualization of the anatomical structures. Although the score for 121 kVp is only two less than 133 kVp, the overall image quality assessed by the assessor for 121 kVp radiographs were overexposed. Thus, it proved that 133 kVp is the optimum tube potential that can be used to expose whole view carabiner. This applied for both open-gate and close-gate position since there was only small changes in image quality for both position. However, the assessors' point of view concerning the overall image quality in terms of exposure (overexpose and underexpose) might be different or misinterpreted. This is due to the fact that, by definition, higher kVp (133 kVp) should give an overexpose image as compared to lower kVp image (121 kVp) since it acts as an influencing factor for the radiographic image density.

Kilovoltage controls the energy of X-ray photon and, hence, the strength of the electron striking the anode target of X-ray tube for any given mAs (Carlton and Adler, 2006). The principle behind radiography is that it deals with the penetration and absorption characteristics of X-ray beam to the test objects or materials. When radiation passes through the test material, some of radiation is absorbed. The factors that govern the process of absorption and penetration are the incoming X-ray photon energy, thickness and density of the exposed material. Hence, by using sufficient energy, it allows visualisation of internal structure and possible imperfection in the exposed object (Mahrok, Juma and Saeed, 2013).

Area of collimation is reduced when imaging the screw view carabiner. Consequently, it increases the intensity of X-ray beam to the metal exposed. As the field size decreases, the amount of scatter radiation will decreases. As a result, the subject contrast will enhance. That is why for screw view, 121 kVp is considered as an acceptable value for optimum image quality of a carabiner. Therefore, it can be deduced that the range of 121 kVp to 133 kVp is possible in order to produce an optimum image quality of screw view carabiner. Again, this range is applied for both open-gate and close-gate positions because there is only little difference exist in the scoring value for both positions.

There was no established rule concerning the appropriate value of mAs or density desired in imaging metals. From the findings of the study, it was found that the increase in mAs did not appear to improve the image quality. Moreover, the assessor stated that the overall image quality of 40 mAs radiograph was overexposed as compared to the other lower values of mAs. From the results, image of 28 mAs seemed to clearly visualise the anatomical structures of the carabiner. Major consideration in evaluating the density of an image is the verification that proper densities are visible throughout the structures (Carlton and Adler, 2006). Hence, 28 mAs is the best choice to be used in imaging the whole view of carabiner.

Next, findings of the study also indicated that there was no obvious difference in changes of the mAs to the image quality of screw view. All of the selected values of mAs were given the same score from 20 mAs to 40 mAs. However, from the assessors' point of view, there was a noticeable difference in the overall image quality, which is the optimal value, is at 28 mAs to 36 mAs. This might be due to the listed criteria of the image that do not cover the overall image quality. As the above discussion, the best choice for mAs in imaging the screw of carabiner is within 28 mAs to 36 mAs.

The number of assessors could be considered a limitation of this study. There was only one assessor utilised for image evaluation throughout this study, which could lead to the research bias. This happened due to the limitation in the availability of qualified assessors within researcher's fraternity for this study since it engages with industrial imaging instead of medical field.

Recommendation for further work

Instead of using only one subject for the study, other types of metals such as aluminium, zinc, copper, etc can be used as subjects so that it will give more significant result as they can be compared between each other. Besides, it is recommended to study used carabiner with known deformities such as crack so that the images can be compared with the new faultless subject.

CONCLUSION(S)

The study has found that the use of medical CR to expose metals such as carabiner is accepted. By manipulating the imaging parameters, CR is able to produce an image of carabiner with a good quality. Regardless of the CR capability to control the density and contrast through post-processing parameters, it is still critical to produce a radiographic image with appropriate exposure factors.

Based on this study, it showed that the optimum values of kVp and mAs in imaging whole view carabiner for both open-gate and close-gate position were 133 kVp and 28 mAs while, for screw view, the preferred range of kVp and mAs were 121 kVp to 133 kVp and 28 mAs to 36 mAs respectively. These combinations applied for both open-gate and close-gate position.

Hence, it is expected that, the technique of imaging the carabiner by using computed radiography would become a baseline for PPE inspection in industrial radiography in the future.

Limitations of the study

Since there was lack of study in investigating the capability of the medical computed radiography to image the carabiner or sort of metals, there was inadequate references and guideline in completing this study. Far little attention has been paid to the use of medical computed radiography as a means to expose the metals.

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REFERENCES

Adams, R. W. (2008). *U.S. Patent No. US7,464,001B1*. Franklin, Pennsylvania: French Creek Production.

Anon, B. C. (2013). *Preliminary study of an innovative non-destructive testing technique concept for detection of surface cracks in non-ferromagnetic materials* (Master thesis). Available from Masters Officials - Master of Aerospace Science and Technology database.

Campbell, F.C. (2013). Inspection methods – Overview and comparison. In F. C. Campbell (Ed.), *Inspection of metals: Understanding the basics* (pp.1-10). Retrieved from http://allaboutmetallurgy.com/wp/wp-content/uploads/2017/06/Inspection%20of%20Metals.pdf

Carlton, R.R. and Adler, A. M. (2006). *Principles of Radiographic Imaging: An Art and A Science.* Clifton Park: Delmar.

Georgiou, G.A. (2011). Non-destructive testing and evaluation of metals. *The encyclopedia of life support systems.* Retrieved from https://www.eolss.net/

Machado, A. S., Oliveira, D. F., Silva, A. S. S., Nascimento, J. R., Simões H., and Lopes, R. T. (2011). International Nuclear Atlantic Conference – INAC. Brazil October 24-28, Analyze image quality and comparative study between conventional and computed radiography applied to the inspection of alloys. Retrieved from http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/43/046/43046426.pdf

Mahrok, M., Juma, T., and Saeed, F. (2013). X-ray radiographic study of simulated voids –like defects in Al castings and welded joints in steel. Journal of Al- Nahrain University. 16(2): http://www.iasj.net/iasj?func=fulltext&aId=74278 (Accessed on 06-06-2016)

Malik, A., Ahmed, W., Ibrahim, H., Abbas, Z., Zahoor-Ul-Din, and Ansari, R. (2013). *Effect of temperature on weld decay of X-42 & x-70 grade steel* (Undergraduate Thesis, University of Mehran, Jamshoro). Retrieved from http://www.slideshare.net/ramizansari/final-thesis-49320468

McDaniels, M. (2013, November 20). Computed radiography offers a range of benefits. *NDT Special Section*. Retrieved from https://www.qualitymag.com/articles/91496-computed-radiography-offers-a-range-of-benefits

Oliveira, D.F., Soares S.D., and Lopes, R.T. (2011). 5th Pan American Conference for NDT. Cancun, Mexico, October 2-6, Inspection of composite pipelines using computed radiography. Retrieved from https://www.researchgate.net/publication/280836384_Inspection_of_Composite_Pipelines_using_Computed_Radiography

Raad, J. A and Kuiper A, A. (2008). Defect discernibility and image quality. In J. A. Raad (Ed.), *Industrial radiography image forming techniques* (pp. 97-103). Retrieve from https://www.gemeasurement.com/sites/gemc.dev/files/industrial_radiography_image_forming_techniques_english_4.pdf