EFFECT OF DIFFERENT APERTURE SIZE OF COLLIMATOR ON YXLON Y.XMB 225 X-RAY SYSTEM TOWARDS FILM DENSITY

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ABSTRACT

Using the YXLON Y.XMB 225 radiographic system and Agfa Structurix D7 films, this study examines the impact of varying collimator aperture sizes on X-ray film density. Two collimators, sized 14 mm × 53.5 mm and 34 mm × 45 mm, were applied to steel specimens under identical exposure parameters, both with and without collimators. Film densities were measured using a densitometer and assessed against the acceptance thresholds specified in ASME Section V. All radiographs met the minimum density requirements, and no significant differences were observed between the different collimator configurations. While density remained largely unaffected, the use of collimators notably enhanced image contrast and reduced scatter radiation. Additionally, the implementation of collimators was shown to lower radiation exposure to personnel, supporting improved safety conditions. Although aperture size has minimal influence on film density, this study highlights the continued importance of collimators in radiographic imaging to improve image quality and ensure radiation safety in industrial applications.

ABSTRAK

Menggunakan sistem radiografi YXLON Y.XMB 225 dan filem Agfa Structurix D7, kajian ini mengkaji kesan saiz apertur kolimator yang berbeza-beza pada ketumpatan filem sinar-X. Dua kolimator, bersaiz 14 mm × 53.5 mm dan 34 mm × 45 mm, digunakan pada spesimen keluli di bawah parameter pendedahan yang sama, kedua-duanya dengan dan tanpa kolimator. Ketumpatan filem diukur menggunakan densitometer dan dinilai berdasarkan ambang penerimaan yang dinyatakan dalam ASME Bahagian V. Semua radiograf memenuhi keperluan ketumpatan minimum, dan tiada perbezaan ketara diperhatikan antara konfigurasi kolimator yang berbeza. Walaupun ketumpatan sebahagian besarnya kekal tidak terjejas, penggunaan kolimator terutamanya meningkatkan kontras imej dan mengurangkan sinaran serakan. Selain itu, pelaksanaan kolimator telah ditunjukkan untuk mengurangkan pendedahan radiasi kepada kakitangan, menyokong keadaan keselamatan yang lebih baik. Walaupun saiz apertur mempunyai pengaruh yang minimum pada ketumpatan filem, kajian ini menyerlahkan kepentingan berterusan kolimator dalam pengimejan radiografi untuk meningkatkan kualiti imej dan memastikan keselamatan sinaran dalam aplikasi industri.

Keywords: X-ray film density, radiography, collimator, image quality

INTRODUCTION

Radiography Testing (RT) is a non-destructive testing method used to examine the internal structure of objects for defects or discontinuities. It involves the use of X-rays or gamma rays to create an image, called a radiograph, that reveals the presence of discontinuities or worse, defects within the object. X-rays, discovered by Wilhelm Conrad Röntgen in 1895, are a form of high-energy electromagnetic radiation with wavelengths shorter than ultraviolet rays and longer than gamma rays. They can penetrate solid substances, making X-ray radiography widely used in identifying indication and weak points in welded components. Radiography testing is widely used in various industries such as aerospace industries, military defense, offshore industries, marine industries, power generation industries, petrochemical industries, and waste management. In general, radiography testing is an inspection method using a radiation source (X-rays or gamma rays) as a medium to detect welding defects that occur on the surface or below the surface, with film as a recorder of the resulting image [1]. X-ray imaging plays a crucial role in ensuring the integrity of welded components. X-ray inspection provides a way to assess internal weld structures and check weld quality for potential defects such as cracks, voids, or irregularities without destroying the component. Radiography testing is one of the Non-Destructive Testing (NDT) method that is broadly used in industry. Also known as Non-Destructive Evaluation to describe measurements that are more quantitative in nature, this method would not only locate a flaw, but it would also be used to measure something about that defect (*e.g.* size, shape, and orientation) as well as to determine material properties (*e.g.* fracture toughness, formability, and other physical characteristics) [2].

X-rays are generated when the cathode or filament such as copper is being heated and releases electrons that will collide with the anode that is positively charged and usually made up from tungsten. In X-ray tubes, its condition is in vacuum, suitable for accelerating electrons toward the target using a high voltage. Upon collision, rapid deceleration leads to the emission of X-rays. There are two ways X-ray is generated, namely by Bremsstrahlung radiation and characteristic X-rays. Bremsstrahlung radiation is the primary mechanism for X-ray production. As the electrons approach the positively charged anode, they are deflected by the electric field. During this deflection, they lose energy, and this lost energy is emitted as X-rays. The emitted X-rays have a continuous spectrum of energy, ranging from low to high. In addition to bremsstrahlung, another process called characteristic X-ray production occurs. When high-speed electrons collide with the inner electron shells of the metal atoms in the anode, they can dislodge these inner electrons. As a result, outer electrons drop down to fill the vacancies, releasing energy in the form of characteristic X-rays. These characteristic X-rays have specific energies corresponding to the energy levels of the involved electron shells [3].

The collimator in an X-ray machine serves a crucial role in optimizing imaging quality and safety of radiation workers. Beam collimators are devices within the X-ray tube housing that align and narrow the X-ray beam with the light field. By ensuring that the light and X-ray fields match each other, collimators help accurately position the X-ray beam towards the area of interest. It is made from high density materials like lead or depleted uranium. Collimator limits the beam size that will decrease scatter radiation, resulting in lower exposure receive by radiation workers. From this, the safe distance of radiation workers from the radiation source will become shorter. Additionally, less scatter radiation also means subject contrast will be improved on the film. Essentially, collimator serve as shapers and directors of the radiation beam, ensuring precision towards the area of interest, minimizing unnecessary exposure from scatter radiation and improving subject contrast on the film [4].

The type of film used in this experiment is D7 under the brand Agfa Structurix. The selection of film also takes into account the desired quality of the radiographic film and the duration of exposure [5]. These films are widely used in non-destructive testing (NDT) due to their superior image quality and rugged behavior. Designed for direct exposure or with lead screens, Structurix D7 is versatile and reliable. Whether using X-rays or gamma rays, it delivers consistent results. D7 film is a high speed and high contrast film due to its coarser grain in the emulsion layer, making it efficient for various applications and better defect recognition. The protective layer consists of Split Antistress Layer (SAL) technology that enhances resistance to pressure, scratching, and creasing [6].

YXLON.XMB 225 is a mobile constant potential X-ray system designed for demanding inspection tasks. Its systems are specifically crafted for challenging inspection jobs in various industries, including power plants, aircraft structures, and petrochemical facilities. The max voltage and current it can reach is 225 kV and 20 mA respectively, while max power it can achieve is 2.25 kW [7]. YXLON.XMB 225 can inspect from low-density composite materials to aluminum and steel [8]. Two default factory made collimators were used in this experiment with the size of (14 mm x 53.5 mm) and (34 mm x 45 mm) that are combined with laser pointer to guide user for more accurate alignment between the x-ray pathway and specimen.

The objective in this experiment is to investigate the effect of varying collimator aperture size on the influence of film density in Agfa Structurix D7 X-ray films. After the film washing process is completed, the radiographic film is evaluated to identify possible defects in the test object by examining variations in film darkness or optical density. C1 collimator which has a dimension of (14 mm x 53.5 mm) and C2 collimator (34 mm x 45 mm) were brought to test. By comparing the radiographic images produced with or without collimator, we aim to determine which one is better in term of density of the film. Throughout this experiment also, we hope to contribute to the ongoing development towards better image clarity and cost effectiveness in the industrial inspection of Non-Destructive Testing.

METHODOLOGY

The experiment was conducted at the bunker of Blok 59, Malaysian Nuclear Agency.

Sample preparation

Two sample were selected namely PLA and EX2 which has a thickness of 14 mm and 15 mm respectively. After that, identification process was done on those sample by placing letters that were made by lead. Two location markers were placed on both side of the sample to indicate the area of interest. Lastly, Image Quality Indicator (IQI) was placed on the sample according to ASTM standards to evaluate the sensitivity of the radiograph. There are two types of IQI that commonly being used which are hole type and wire type. Figure 1 shows IQI hole type number 20 has been selected with a shim that has a thickness of 5 mm for PLA plate. IQI number 20 indicates that the thickness of the IQI is 20/1000 which is equivalent to 0.02 inch or 0.508 mm. The sole purpose of shim is to make the IQI parallel to the weldment cap.

Figure 1. Completed sample with identification, location markers and Image Quality Indicator (IQI) for PLA sample

Film Preparation

Film preparation was done in a dark room and by using a specific red safelight to avoid the film being exposed by light that will cause film fogginess. Before turning off the white light, film cassette was inspected to check for any hole or leakage while lead screen was thoroughly checked for any dented, scratches or any chemical that will interfere with the film quality. Then, the safelight was on, and the white light was turned off. During the loading process, we handled the film only by its edges to avoid any artefacts on the film. Then, the film was carefully placed between two lead screens which the front of the lead screen will intensify the production of electron, and the back will absorb the backscatter radiation. Following that, the film couple with the lead screen will be placed into the film cassette to protect it from the light and surroundings. Lastly, the cassette was sealed with masking tape to prevent any light leakage and was labelled clearly for identification. This whole process was done to make sure the film prepared free from imperfections or artefacts that may interfere with the quality of the film.

Figure 2. Film cassette and Agfa Structurix D7 film

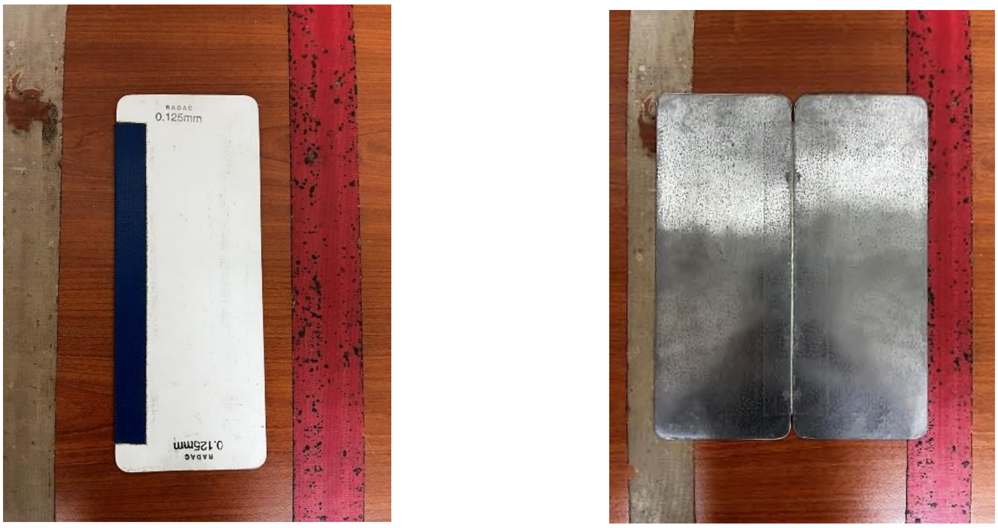


Figure 3. Lead Screen

Radiation Setup

The radiation setup was started by setting the Focal to Film distance to be 700 mm. 700 mm was chosen because it surpasses Focal to Film (FFD) minimum for sample PLA and EX2. FFD_{min} is the shortest allowable distance between the X-ray source and the film tp get adequate image resolution and contrast. Equation 2.1 shows the formula for FFD_{min} while Equation 2.2 and Equation 2.3 shows calculation of FFD_{min} distance for both samples PLA and EX2 respectively.

$$\boldsymbol{FFD}_{\min} = \boldsymbol{t}(\frac{F}{\mu_{gmax}} + 1) \quad (1)$$

where t = Sample thickness (mm), F = Focal spot size (mm) and μ_{gmax} = Maximum geometrical unsharpness

$$FFD_{min} = 14(\frac{0.4}{0.508} + 1) \quad (2)$$
$$= 25.02 \text{ mm}$$
$$FFD_{min} = 15(\frac{0.4}{0.508} + 1)$$
$$= 26.81 \text{ mm} \quad (3)$$

Measuring tape was used to accurately set the distance between the focal spot and the film, as required for this experiment. Next, Collimator 1 (C1) and Collimator 2 (C2) were installed on X-ray machine's head tube as shown in Figure 5. Laser pointer also has been used to visually guide for proper alignment between the focal spot and the specimen. The alignment is very crucial so that the X-ray beam would radiate the area of interest that will lead to increased density of that specific area on the film. Once the alignment process is done, the laser pointer was returned to its original position to avoid any interference during the X-ray exposure. Lead sheets were placed below and nearby sample to absorb backscatter radiation that can affect subject contrast on the film.

Figure 4. Radiation Setup

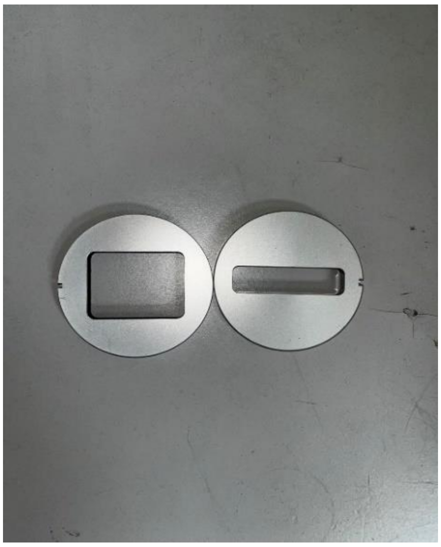


Figure 5. Collimator 1 (C1) and Collimator 2 (C2)


Figure 6. Collimator Installation

YXLON Y.XMB 225 X-RAY SYSTEM Operation Procedure

In the control panel, input such as voltage, current, focal spot and irradiation time were key-in into the YXLON 225.XMB. For this experiment, the voltage, current, focal spot and irradiation time were 180 kV, 4.4 mA and 0.4 mm respectively. Irradiation time for PLA sample was 27 seconds and for EX2 sample was 34 seconds. After the input process was done, we then placed the X-ray film directly below the specimen and ensured that it was aligned with the focal spot and the area of interest of the specimen. Next, we activated the YXLON Y.XMB 225 X-ray System by turning it to the right, positioning it to the “<⚡>” setting. After that, we ensure that nobody is inside the bunker before closing the lead door. Lastly, the switch outside the bunker was turned to the right followed by the safety key. The red light will shine as shown in Figure 6, indicating that the X-ray machine is radiating X-ray. It is very important to wait for the red light on the control panel and at the stairs in the bunker turn off before entering the bunker. Survey meter was used to check if there is any radiation leakage at the gap of the lead door. Once both red lights were turned off, we turned the switch key to the left, removed the key and placed it back in its box. Next, we opened the lead door, remove the sample and the film, then turn the main switch to the left and set it to the “< O >” position. Finally, the key was removed from the control panel of the X-ray machine. These detailed procedures ensure that the safety of the radiation worker is not being compromised while protecting the quality of the radiograph. During this time also, the latent image has already existed in the emulsion layer, waiting to be develop into visible image.

(a) Input in the X-ray

(b) Key in at the control panel

Figure 7. X-ray machine features

Film Processing

After irradiating the sample, the film was processed in a control dark room where safelight was utilized during the process. Exposed films undergo several chemical immersions. Firstly, the most crucial part, the development process. At this process, the developer which is alkaline solution will reduce the exposed silver halide crystals in the film emulsion to metallic silver, transforming latent image into a visible image. After that, stop bath, which is an acidic chemical, will stop the development process by neutralizing the developer. Following the stop bath process, films were immersed in a fixer which also an acidic solution that will dissolves the unexposed silver halide crystals, making the image permanent and light resistant. Next, the films were thoroughly washed in running water to remove any residual chemicals that is important to prevent image degradation over time. After that, film will be immersed in photoflo for 30 seconds that contain some soap to avoid sticky and watermark on the films. Lastly, films were dried in a dryer for 15 minutes. The proper drying duration also is essential to avoid streaks or artefacts that could affect the image quality.

Figure 8. Film Processing

Figure 9. Viewer and Densitometer

Film Viewing

During this phase, films were tested its density using densitometer. Film density refers to the degree of darkness of the film. According to ASME Section V, Article 2, the acceptable radiographic film density for single-film viewing shall range between 1.8 and 4.0, provided that the image quality indicator (IQI) sensitivity requirements are satisfied [9]. If the density is less or more than the range, the film will be rejected, and irradiation process shall be repeated. To check the density of the film, the film was moved to the left while the pointer of the densitometer was static. There are 3 places on the film to check its density which are left, middle and right. If the density is sufficient, the films will be inspected to see if there are any artefacts in the area of interest that will cause the film to be rejected also. Only film with sufficient density and free from artefacts on the area of interest will undergoes film interpretation process.

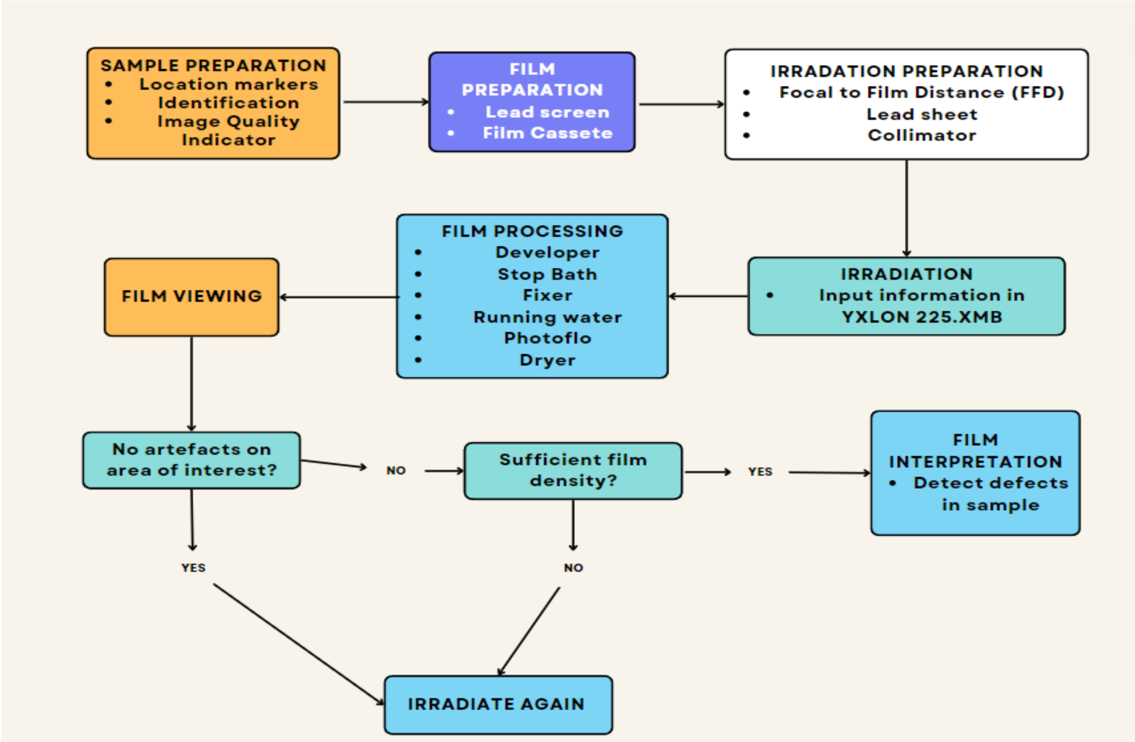


Figure 10. Flow chart from Sample Preparation until Film Interpretation

RESULT AND DISCUSSION

Table 1 shows the comparison of film density for PLA sample with and without collimator. Sample with installation of collimator has been labeled C1 and C2.

Table 1. Density film with and without collimator for PLA sample

Sample	Volt (kV)	Current (mA)	Time (Sec)	Thickness (mm)	Density			Accept/Reject
PLA7					2.10	2.21	2.28	
PLA8					2.05	2.14	2.14	
PLA9C1					2.04	2.20	2.02	
PLA10C1	180	4.4	27	14	2.08	2.12	2.20	Accept
PLA11C2					2.08	2.09	2.21	
PLA12C2					1.81	1.82	2.15	

Table 2 shows the comparison of film density for EX2 sample with and without the use of collimator.

Table 2. Density film with and without collimator for sample EX2

Sample	Volt (kV)	Current (mA)	Time (Sec)	Thickness (mm)	Density			Accept/Reject
EX23					2.79	2.29	2.34	
EX24					2.59	2.39	2.34	
EX25C1					2.17	2.45	2.21	
EX26C1	180	4.4	34	15	2.25	2.36	2.11	Accept
EX27C2					2.17	2.14	2.11	
EX28C2					2.47	2.27	2.08	

Both PLA and EX2 samples were being irradiated with the same voltage and current which are 180 kV and 4.4 mA respectively. Only exposure time and thickness of the sample that set both samples apart. For PLA sample that has a thickness of 14 mm and exposure time of 27 seconds, the density of the films recorded were consistent and within acceptable range of 1.8 to 4 according to ASME V, with average density of PLA7 is 2.20 while for PLA8 is 2.11. After the installation of the collimator 1 (C1) and collimator 2 (C2), average density of the film for PLA9C1, PLA10C1, PLA11C2, and PLA12C2 are 2.09, 2.13, 2.13, and 1.93 respectively. For EX2 sample on the other hand that has a thickness of 15 mm and exposure time of 34 seconds, its average densities for EX23 and EX24 are 2.47 and 2.44. With installation of collimator, its average densities for EX25C1, EX26C1, EX27C2, and EX28C2 are 2.28, 2.24, 2.14, and 2.27 respectively.

The result of this experiment shows all the film for both samples capable of producing high quality images for both the 14 mm and 15 mm steel samples. The films met the required optical density standards, showing that our chosen exposure time was suitable for the material properties. However, the average density obtained with and without the use of collimator shows no significant change for either samples PLA or EX2. This is due to the fact that the collimator does not increase the intensity of the radiation. Even though the radiation is focused on a certain area, the intensity is still the same. It just changes the mode of radiation from panoramic to focus on certain areas of interest. On the other hand, collimator can improve subject contrast on the film due to the scattered radiation is less because the aperture size of the window is decreasing. It also can attenuate the radiation so that dose received by radiation workers will be less, hence shortening the boundary and safe distance from the source. Figure 11, Figure 12, Figure 13, and Figure 14 show film quality of PLA and EX2 sample without and with the aid of collimator.

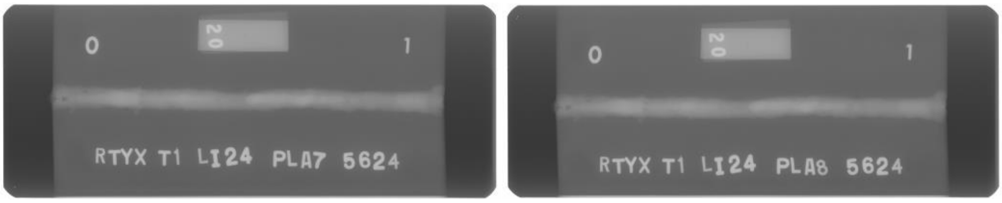
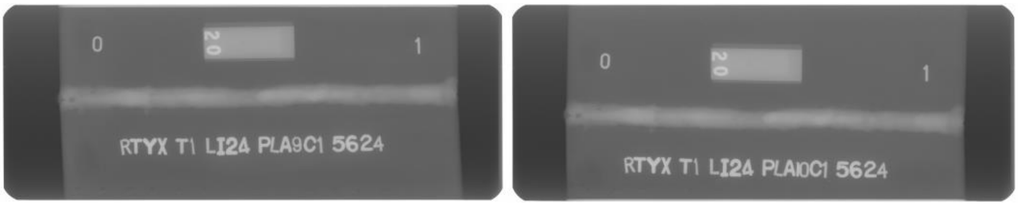
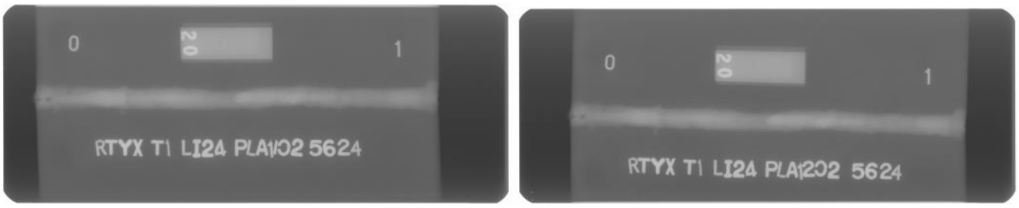


Figure 11. Film quality of PLA sample without collimator



a) b)



c) d)

Figure 12. Film quality of PLA sample with collimator. a) and b) using C1. c) and d) using C2

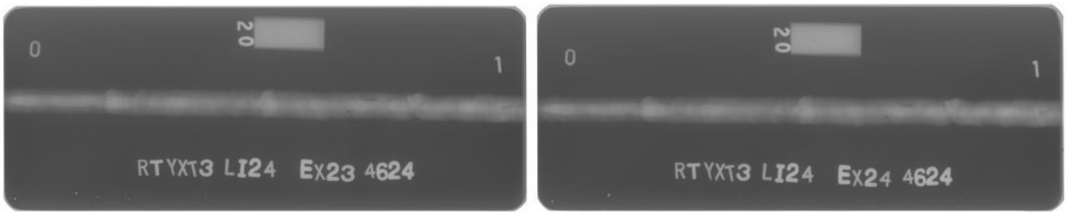
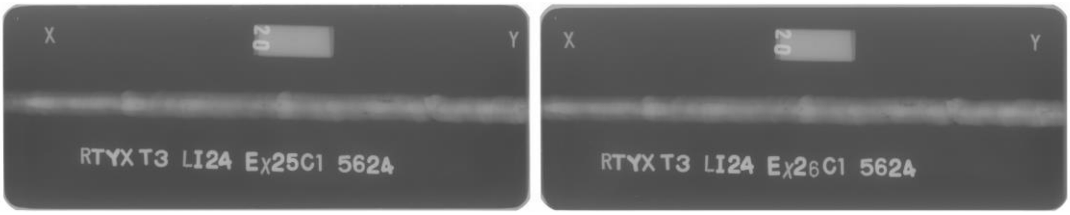
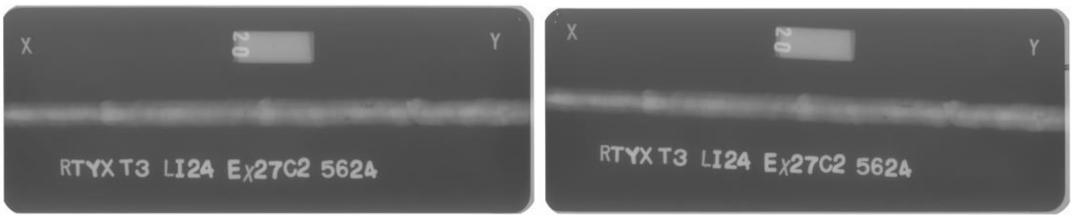


Figure 13. Film quality of EX2 sample without collimator



a) b)



c) d)

Figure 14. Film quality of EX2 sample with collimator. a) and b) using C1. c) and d) using C2

CONCLUSION

In conclusion, this experiment serves as evidence that the use of collimator will have no significant effect towards film density Agfa Structurix D7. However, the use of collimator improves the subject contrast on the film due to decreasing scatter radiation, shorten the safe distance from the source and decrease the dose received by the radiation workers so that the dose receive is considered safe and will be in accordance with the standard and safety regulations.

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