DEVELOPMENT OF AN IMPROVED WOOD'S ALLOY END-FRAME CASTING UNIT FOR ELECTRON FIELD SHAPING IN RADIOTHERAPY

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Abstract

As the second leading cause of death, cancer is a harsh reality. Skin cancer is one of the most prevalent cancers in South Africa and is commonly treated using electron radiation in radiotherapy. The applied radiation field needs to be shaped to the size of the cancer-affected area on the patient. This can be achieved through end-frames that fit into applicators that attach to the treatment unit. The end-frames are produced by casting Wood's alloy into commercially available jigs. However, producing these end-frames presents various shortcomings such as lack of dimensional accuracy, the inconsistent density of the castings and the high cost of the jigs. The aim of this study was to develop a Wood's alloy casting unit that can be made available to local oncology departments to produce end-frames that are superior to what can be produced through commercial jigs. This paper describes the development and manufacturing of the new casting equipment and experiments performed to evaluate end-frames produced. Results showed that end-frames cast in the newly developed casting equipment are dimensionally more accurate, have consistent high density, and can be produced in a shorter time.

Keywords: Electron field shaping, Wood's alloy, casting-jig, radiation therapy.

1. INTRODUCTION

Technology for treating cancer has vastly improved in the past few decades. Today specialists can use different technologies to detect, plan and treat cancer with a much higher success rate (Mutter, Bouras & Marescaux, 2005). Despite these new technologies, cancer is still the second most prevalent cause of death after cardiovascular disease. The number of new cases diagnosed each year is still increasing. It is predicted that the number of cases worldwide will nearly double and that South Africa alone will see a 78% increase by 2030 (Kulendran *et al*., 2013; Bray *et al*., 2012).

Standard treatment of skin cancer is mainly surgery; however, the treatment option depends on the type, stage, size and location of the cancer, as well as the age and health of the patient. In some cases, especially where the cancer is more advanced, treatment can include a combination of extensive surgery, immunotherapy and radiation therapy (Simões, Sousa & Pais, 2015). This study focuses on electron radiation therapy of skin cancer as administered by a linear electron accelerator or LINAC for short.

During radiation therapy, the ideal is to treat only the cancer-affected area with minimal exposure to healthy tissue because of the damaging effect radiation has on cells. The smaller the area of healthy tissue irradiated, the quicker the area can recover since the wound heals through reparative growth of the surrounding healthy tissue after treatment. However, a small amount of healthy tissue surrounding the cancerous area needs to be irradiated to eliminate any micro spread of cancer cells to the adjacent areas (Gregoire, Scalliet & Ang, 2004; Tobias & Hochhauser, 2015).

1.1. Radiation field collimation

The electron radiation treatment beam should be collimated close to the skin due to the electrons scattering in the air (Cherry & Duxbury, 2009). A few techniques exist for secondary collimation, but the standard for electron treatment is to use applicators (Inyang & Chamberlain, 2015). The applicator attaches to the LINAC head and consists of a series of trimmers made to collimate the electron field. At the end closest to the patient, a cut-out or end-frame made of a high-density material is fitted to collimate the field further closer to the treatment area. The end-frames supplied with the LINAC usually have a square or round treatment portal. The portals are produced in one-centimetre-size increments and chosen to fit the treatment area as closely as possible (Strydom, Parler & Olivares, 2005). Custom-made end-frames cater for the field sizes between the sizes of the standard end-frames and irregularly-shaped treatment areas. These end-frames are often produced in the hospitals where the LINACs are installed.

1.2. Producing end-frames for electron field shaping

End-frames were traditionally machined from lead, with the thickness measured in millimetres, an amount, half the numeric value, measured in Mega electron Volt, of the incident energy, i.e. 20 Mega electron Volt (MeV) = 10 mm (Halperin, Perez & Brady, 2008). However, producing the lead end-frames was labour-intensive, requiring precision machining. The lead end-frames can be easily damaged when dropped and need careful handling. Once damaged beyond repair, the end-frames had to be discarded since most workshops at hospitals were not equipped to recycle the lead, resulting in environmentally unfriendly waste.

End-frames are now commonly produced through casting Wood's alloy into commercially available jigs. Wood's alloy is a fusible eutectic alloy (a single melting point lower than each of the individual materials). It is composed of bismuth, lead, tin and cadmium (approximate 50% Bi, 25% Pb, 12.5% Sn and 12.5% Cd by weight) with a liquidus (completely liquid) melting point that ranges from 70 °C to 78 °C. The thickness required is usually 1.21 times the thickness required for lead, i.e. 12 mm for 20 MeV (Khan, 2010:243; Belmont Metals, 2018; Reade International Corp., 2018).

Due to the low melting point of the material, it can be easily melted in hospital workshops for casting. If an end-frame is damaged beyond repair, it can be recycled by simply re-melting and re-casting. Jigs for casting Wood's alloy end-frames are commercially available for Elekta, Siemens and Varian LINACs. Suppliers include Aktina Medical, New York (Figure 1), and Radiation Products Design Inc (RPDinc), Minnesota.

Figure 1: Siemens electron beam shaping system by Aktina Medical (Aktina Medical, 2018)

Initial testing was performed to evaluate end-frames produced using an Aktina Medical casting-jig by casting several Wood's alloy end-frames. The authors observed the results, and the following concerns were highlighted at the hand of existing knowledge on the cooling of eutectic alloys from literature:

- The jig has to be imported at a high cost.
- Producing a large end-frame with a large treatment portal results in a thin alloy frame. When casting the Wood's alloy end-frames, the material solidifies before it flows around the entire polystyrene block used to form the treatment portal, thus causing a cold shunt (proper fusing of metal streams (Rajkolhe & Khan, 2014). This is more apparent at lower ambient temperatures.
- As the alloy temperature decreases after casting due to heat transfer to the cooler surroundings, it starts to solidify. This follows the solidification front, which is the border between the liquid and solid area, i.e. the outer area will solidify first. Most materials reduce in volume as they solidify and attract the inner liquid volume towards the solid front causing

internal shrinkage cavities. The Wood's alloy cast in the jig also solidifies from the top surface exposed to air at ambient temperature and forms cavities in the casting upon contraction of the alloy during further cooling. These cavities were observed by cutting through the castings produced using the commercial jig. Cavities will reduce the density of the end-frames, which is vital to its' shielding ability.

- Bismuth is one of the few elements that expand upon freezing, i.e. less dense in solid than liquid form (Stoll, 2017). Due to the bismuth component in Wood's alloy, it also expands after initial shrinkage during cooling (Metaconcept Groupe, 2018). This will likely cause the outer dimensions and the end-frame holes to be slightly larger than the intended dimensions. Since the end-frames fit into the applicators with close tolerance, expansion may cause problems fitting the end-frames. An increase in the size of the treatment portal will cause a larger area to be irradiated than intended.

This study aimed to develop a Wood's alloy casting-jig with locally available materials and equipment to improve commercially available casting-jigs. Each of the problems identified with the commercial jigs was considered separately, and an iterative research process was applied with each iteration improving on the previous until a feasible solution was found.

The experimental work for this study was performed on an SL25 LINAC from Elekta at the Oncology Department at the National Hospital in Bloemfontein, South Africa. This is a typical treatment unit used in the irradiation of cancer. With Elekta-type LINACs, the end-frames slide into the end closest to the treatment area of the applicator (Figure 2a & b). Two locating pins are mounted in the frame of the applicator and protrude into holes in the end-frames. This ensures the correct positioning of the end-frames.

Figure 2a: Elekta electron applicator

Figure 2b: Shaped end-frame

To ensure that the correct size end-frame is fitted for each treatment, Elekta LINACs use a binary coding system. Four microswitches built into each applicator register the code for the end-frames when inserted (Van der Walt, 2009:84). When the end-frames are produced, a binary code is allocated for each frame according to a list of sizes from Elekta.

2. MATERIALS AND METHOD

2.1. Casting-jig with repositionable strips

The authors' first attempt at a Wood's alloy casting-jig consisted of a 5 mm steel baseplate with repositionable aluminium strips to provide for all applicator sizes used with Elekta LINACs (Figure 3). The strips attached to the baseplate with M5 bolts were screwed into threaded holes in the baseplate. Provision was made for the locating and binary code holes required in the end-frames.

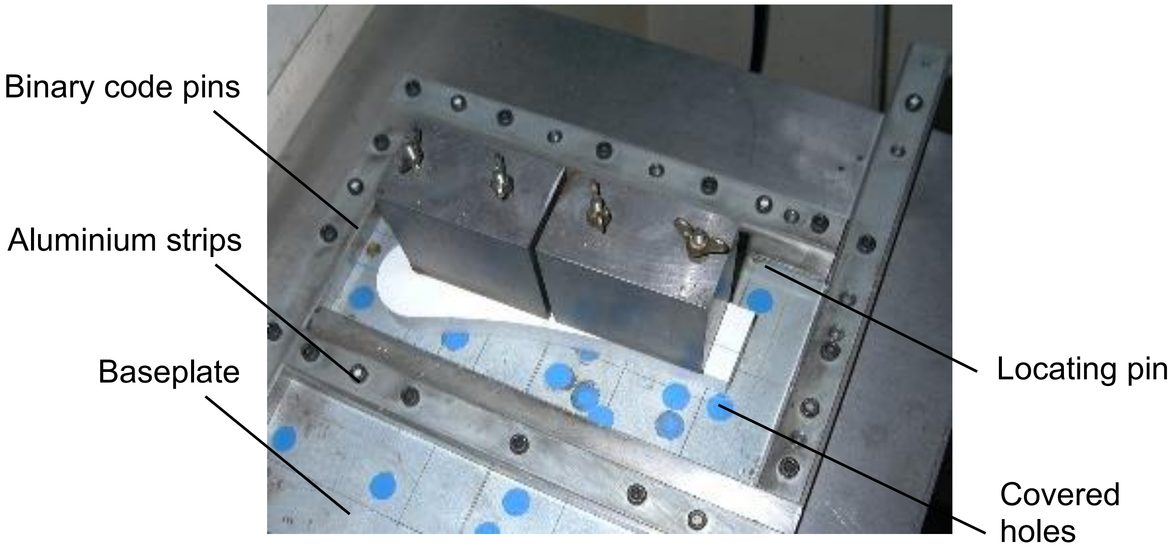


Figure 3: Casting-jig with repositionable strips

In preparing to cast a specific size end-frame, the four aluminium strips were positioned and bolted down through the holes provided for that size. The unused holes that fall within the boundary made by the strips were closed with small round stickers to prevent the molten Wood's alloy from leaking during casting. The treatment portal in the end-frame could be created by a polystyrene block or high-density fibreboard cut-out, centred on the jig and weighed down to prevent it from floating while casting the end-frame. Once cooled, the aluminium strips were loosened and the end-frame removed for final finishing. The inserts can be painted using a spray can to make the inserts safe to handle, considering the lead and cadmium content of the alloy.

Problems experienced with the casting-jig with repositionable strips:

- Similar to the commercial casting-jig, when casting a large end-frame with a large treatment portal, the Wood's alloy solidifies before it completely flows around the entire polystyrene block, causing a cold shunt. A solution could be to heat the base of the jig to the melting point of the Wood's alloy before casting.

- The Wood's alloy cast in the jig also solidifies from the top surface exposed to ambient temperature, thus forming a shell that leads to the formation of cavities inside the casting. According to literature (Dea & San Luis, 1988), problems associated with cavities forming in Wood's alloy can be prevented by rapidly cooling the alloy from the bottom upwards.

A heating/cooling block was produced to overcome the problems experienced with the casting-jig with positionable strips. The block contained a continuous 8 mm copper tube that was bent zigzag in the X direction followed by the Y direction to form a grid with one inlet and one outlet. A foundry cast aluminium around the tube to form a block which was machined afterwards to the required dimensions (Figure 4).

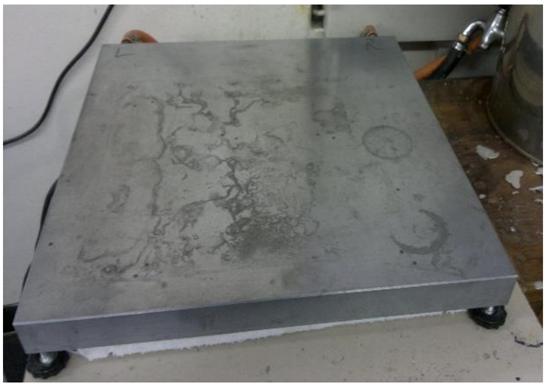


Figure 4: Heating/cooling block

With the casting-jig placed on the block, it was heated up to the melting point of the alloy at 78°C by passing hot water through the block. Once the Wood's alloy was cast, the casting-jig could be cooled by circulating cold tap water through the block. Infra-red images were taken of the top surface of the block with a FLIR E60 camera at 20-second intervals. The ambient temperature was 26.4 °C, and the cold-water supply temperature was 25.4 °C with a flow rate of 1 L/min. The images showed uneven cooling of the block, with cooling first taking place from the top right where the cold water entered (Figure 5). Uneven cooling of the cast end-frames is not desirable since it may cause uneven solidification and possible porosity inside the casting.

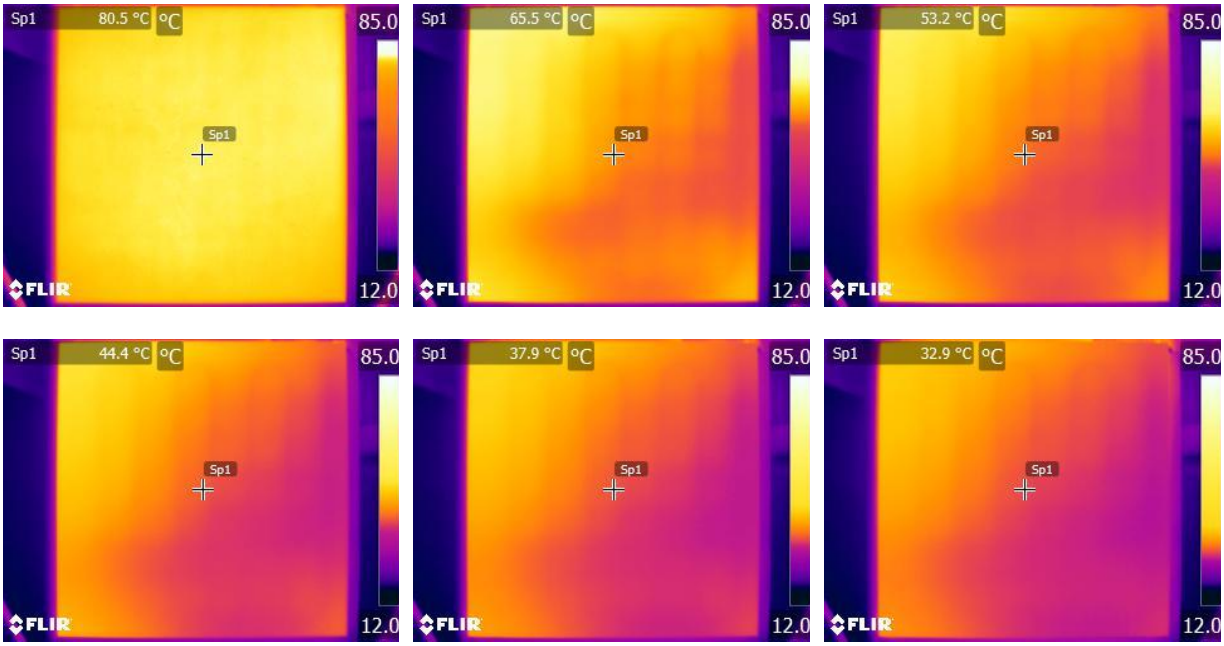


Figure 5: Infra-red images of cooling of the top surface of block taken at minute intervals

Conclusion on effectiveness of casting-jig with repositionable strips

The casting-jig with repositionable strips successfully incorporated all features required of Elekta end-frames in the cast product with no additional milling or drilling required. To produce a Wood's alloy end-frame took about one hour using the casting technique with the casting-jig placed on the heating/cooling block. To produce the same size end-frame from a sheet of lead using conventional machining would take about five hours. Some features could, however, be improved:

- Positioning the strips and fastening the bolts to set up an end-frame size on the jig, as well as loosening the bolts to remove the cast frame after cooling, was time consuming.

- Covering all unused holes within the cast boundary with stickers proved cumbersome.

- The baseplate of the casting-jig warped slightly when heated on the block. This caused a reduced contact area between the baseplate and the heating/cooling block, resulting in uneven heat transfer.

- Uneven cooling of the casting surface resulted in uneven cooling of the end-frames that were produced.

2.2. Optimised casting unit

The problems associated with the casting-jig with positionable strips and heating/cooling block were considered, and a new casting unit was designed and fabricated. The intention was to incorporate all the system components, such as the casting-jig, heating/cooling block, urn, pump and Wood's alloy melting pot, into a single unit. This unit could then be made available to oncology departments to cast end-frames as required with little effort.

In order to ease the process of configuring the casting-jig for each different end-frame size, a separate casting-frame for each size commonly used with Elekta LINAC applicators was produced. The casting-frames were designed to split into two halves along their diagonal corners held together with quick-release clamps (Figure 6). Toggle clamps are used to keep the casting-frames in position on the base, eliminating the need for holes to bolt the frames as per the previous casting-jig shown in Figure 3.

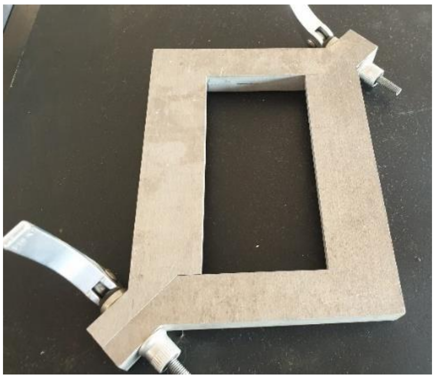


Figure 6: Casting-frame with quick-release clamps

In order to eliminate the problem of the baseplate warping, all features of the previous baseplate were incorporated into the new cooling block, which acts as the base for the casting-frames. The layout of the channels inside the new block also had to be changed to improve on the uneven cooling observed with the previous heating/cooling block. Several cooling channel layouts were designed on a computer-aided design (CAD) program (SolidWorks™). The focus was placed on flow trajectories in the channels to ensure flow in all channels. In the final design, the block was divided into quadrants, each with its inlet and outlet. The channels follow a spiral design to aid even cooling (Figure 7).

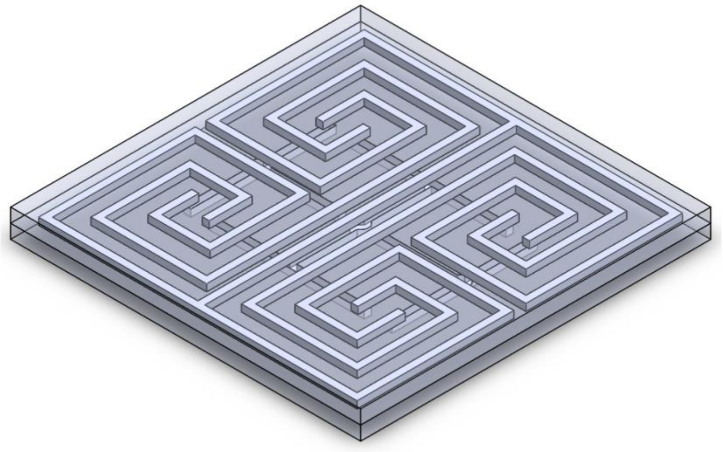
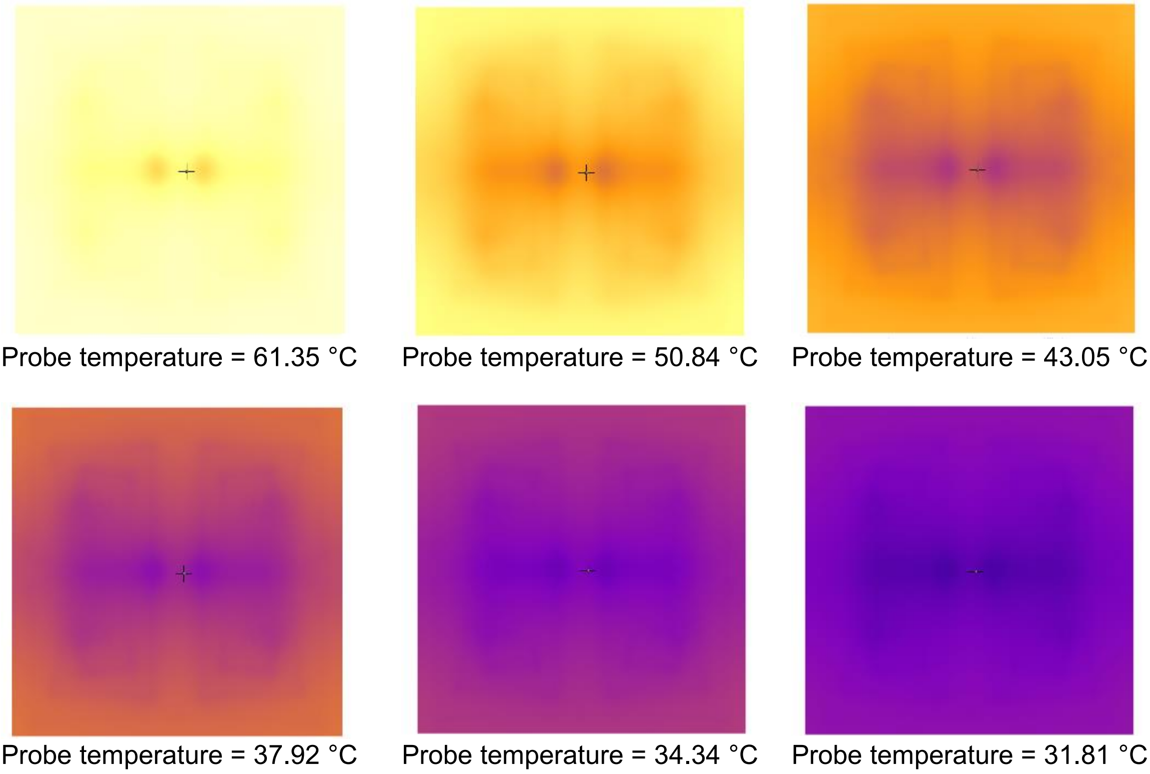


Figure 7: Optimised concept of cooling channel layout

The final concept of the cooling channel layout was then simulated on Ansys simulation software to determine if even cooling of the top surface would take place. Aluminium was indicated as a cooling block material with ambient and water temperatures set at 25°C and a flow rate of 1 L/min for the simulation. A summary of results taken at 20-second intervals is shown in Figure 8.



Probe temperature = 61.35 °C Probe temperature = 50.84 °C Probe temperature = 43.05 °C

Probe temperature = 37.92 °C Probe temperature = 34.34 °C Probe temperature = 31.81 °C

Figure 8: Ansys cooling simulation results of the block of the optimised casting unit at 20-second intervals

Similar to the infra-red images shown in Figure 5, infra-red images were taken of the cooling block of the optimised casting unit once manufactured. Figure 9 shows a summary of the images at 20-second intervals. The ambient temperature was 26.6 °C, and the cold-water supply was 25.5 °C with a flow rate of 1 L/min.

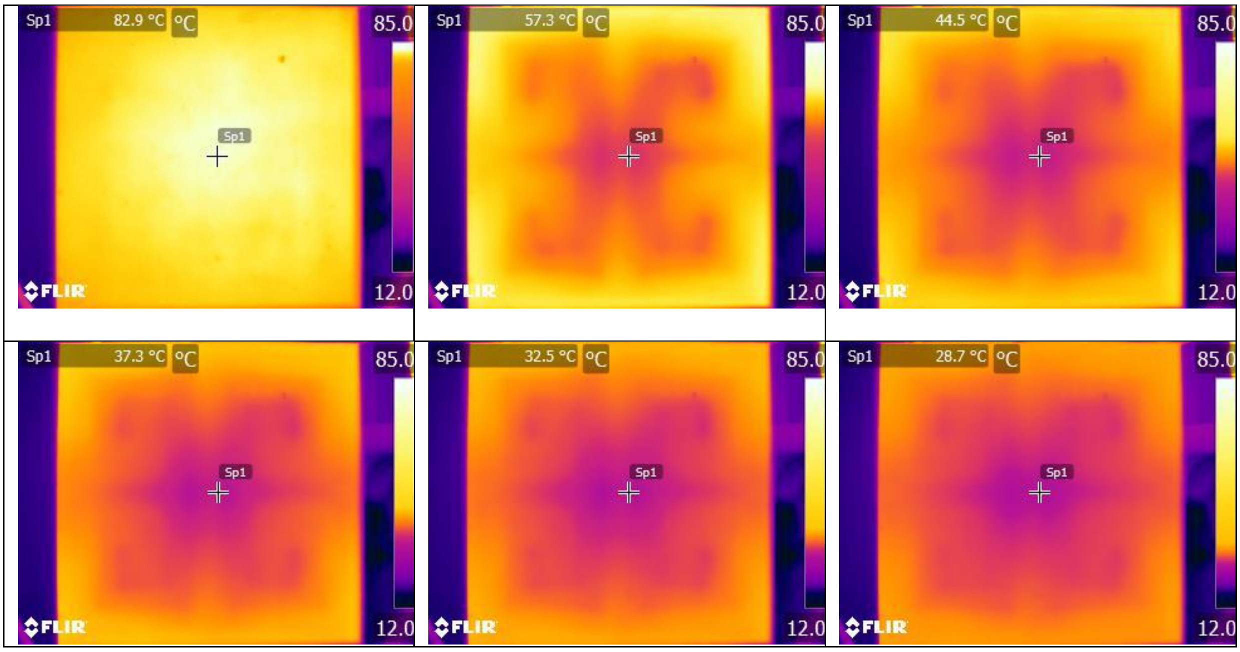


Figure 9: Infra-red images of the block of the optimised casting unit showing the cooling effect at 20-second intervals

The images show a more centred cooling effect with a much less steep temperature gradient across the surface while cooling compared to the previous block design. It furthermore correlates well with the cooling simulation performed on the CAD model using Ansys.

As explained at the end of Section 1.2, provision needs to be made on the block for the binary coding system used with the end-frames. The system reads the binary code from the same top right-hand corner at the same distance, irrespective of the size of the end-frames, as shown in Figure 11a. Four holes were drilled into the block at the appropriate position. The holes were threaded, and brass pins, with a slot cut into the top of each, were then screwed into each hole. To create a hole in the end-frames representing 1 in binary, the pin should be partially unscrewed to stand proud of the surface. The pins remaining flush represent 0 in the binary system. The casting-frame had to be accurately located to ensure that the binary code holes were created at the same position in the top right corner of the cast end-frame. A recess was milled into the top surface of the block that allowed for all frames to be placed in the same position according to their top right corner against the locating edges (Figure 10 a and b).

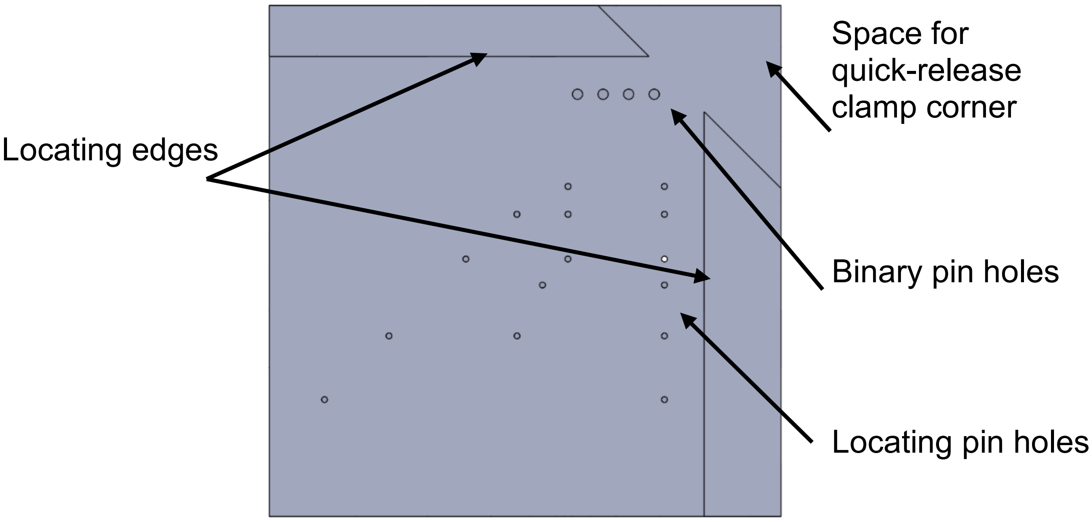


Figure 10a: CAD representation of the top surface of optimised casting unit cooling block

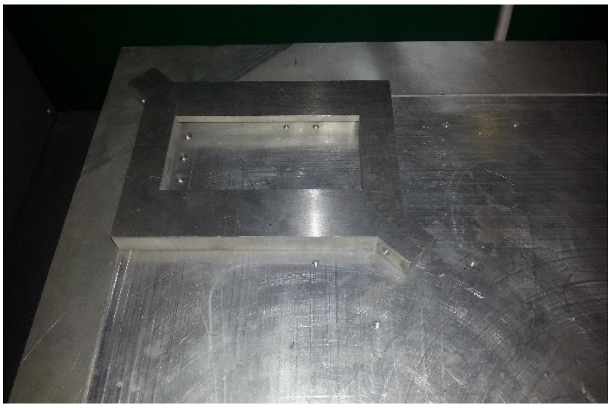


Figure 10b: Manufactured block with casting-frame in position

Provision was also made for locating holes required in Elekta LINAC end-frames. A similar approach was taken to that used for the binary code. When a specific size end-frame has to be cast, the locating pins for that end-frame are partially unscrewed to stand proud of the surface of the block and thus create the locating holes in the end-frame. Unused locating pins remain flush and thus close the hole made in the block.

Hot or cold water is pumped through the system to heat or cool the block. Hot water is pumped with a circulation pump from an urn to the block through an insulated pipe system. It then flows through the channels and back to the urn to form a closed loop. Local tap water is used to cool the block. The supply is under normal municipal pressure, sufficient for the water to flow through the channels. The water flows through the block and is then discarded through a pipe to a sink or other means. Since the hot and cold water uses the same inlet and outlet of the block, the water flow is controlled by solenoid valves. A cabinet was designed (Figure 11 and 12) to incorporate all parts of the new casting equipment.

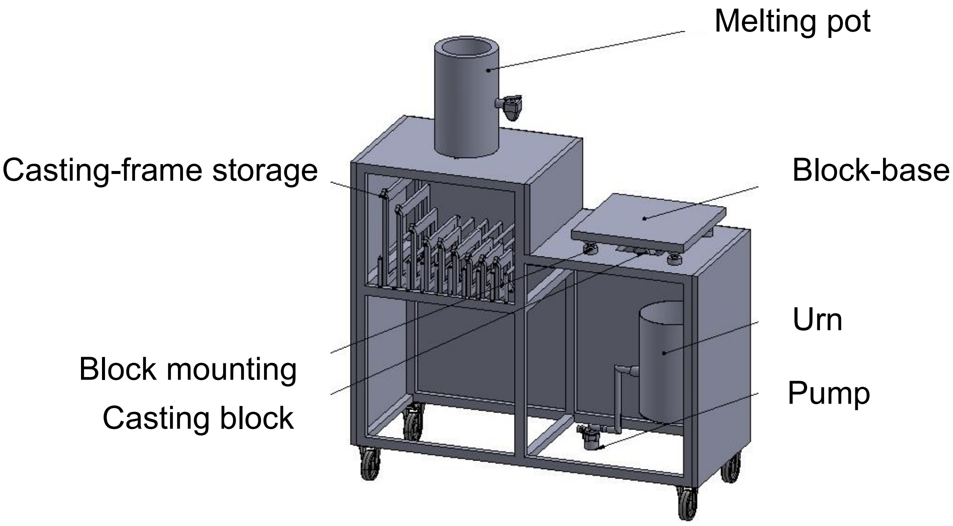


Figure 11: CAD representation of casting unit

Figure 12: Manufactured casting unit

The design intended to provide a place for the block, urn and pump system, Wood's alloy melting pot, storage for casting-frames and manufactured end-frames or new alloy stock in a single unit.

2.3. Evaluation of cast end-frames

2.3.1. Dimensional accuracy of end-frames

The optimised casting unit was evaluated by comparing the dimensional accuracy of end-frames produced with the unit to end-frames cast in a commercial jig from Aktina Medical. The Aktina jig utilises rubber frames to form the outer dimensions of cast end-frames. Because of the flexible nature of rubber, this may allow expansion of the Wood's alloy end-frame to take place while cooling. Although the Aktina Medical commercial jig is meant to cast end-frames for Siemens LINACs instead of Elekta LINACs, which this study focuses on, the principle of operation remains the same.

Three end-frames sizes were selected for both the commercial jig and the developed casting unit (small, medium and large) to evaluate the dimensional accuracy of the end-frames cast. Since Siemens and Elekta applicators are not the same size, the dimensions of the end-frames were also not the same, but sizes were selected as close as possible to the sizes used for the commercial jig. The sizes (in mm) selected were 103 x 103, 150 x 150 and 200 x 200 for the commercial jig and 90 x 90, 130 x 130 and 170 x 170 for the optimised casting unit. For each jig size, end-frames were cast with two different portal sizes. The portal sizes were selected to create an end-frame border width (Figure 13) that was approximately the same for the two types of jigs (one in the range of 15 mm and another in the range of 35 mm). This was to evaluate whether the size of the treatment portal in the end-frames influences the expansion of the Wood's alloy. A solid end-frame was also cast for each size to determine if the frame would expand more with the maximum volume of alloy cast.

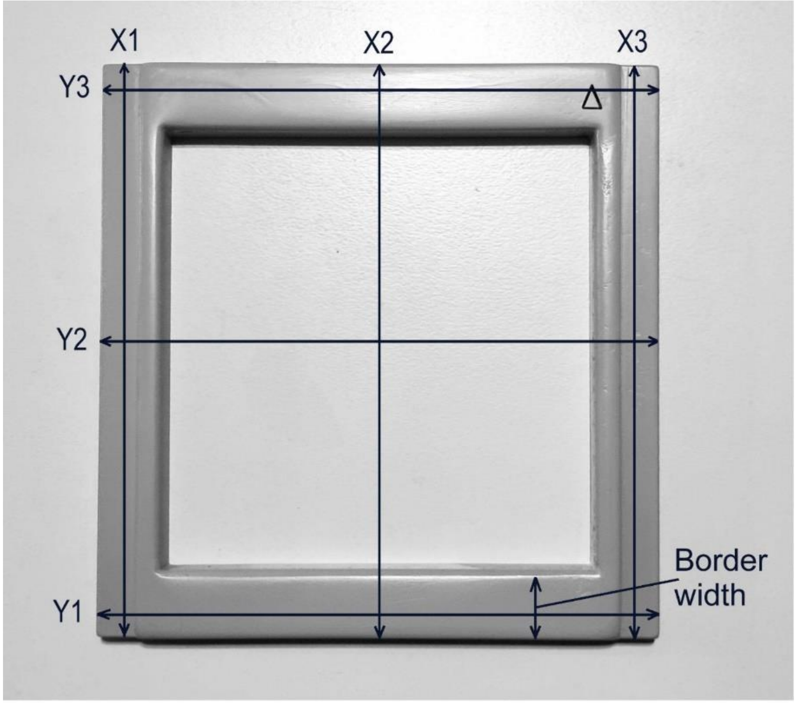


Figure 13: Cast end-frame showing positions of dimensional accuracy measurements

The outer dimensions of the cast end-frames were measured with a Mitutoyo digital Vernier calliper at the corners and in the middle of each end-frame in both the X and Y-directions (Figure 13). This was repeated three times at each position, and the average measurement was calculated.

2.3.2.Production time of end-frames

The cooling rates of Wood's alloy for both the commercial and new jig were established to determine if the new casting unit reduces time in producing end-frames. This was done by casting solid 100 mm x 100 mm end-frames with the Aktina Medical jig and the optimised casting unit. The commercial jig was allowed to air cool at an ambient temperature of 24.6 °C while the optimised casting unit was cooled with water at 22.7 °C. In both cases, the temperatures of the cast Wood's alloy were logged with a 10 kΩ thermistor that was connected to a NI-USB 6009 data acquisition unit from National Instruments. The data acquisition unit was connected to a laptop that ran a program written in LabView to log the temperatures measured by the thermistor.

2.3.3.Density of cast end-frames

To determine the effect of the new casting unit on the density of the cast end-frames, three 100 mm x 100 mm end-frames were cast using the commercial and optimised casting unit. The commercial jig castings were left to air cool at room temperature, and the optimised casting unit castings were fast cooled. For this experiment, treatment portals were not included in the end-frames to increase the visibility of any cavities that may have formed. The top surfaces of all the cast end-frames were machined on a CNC milling machine to a thickness of 12 mm. A uniform thickness was required to perform density comparisons between the different castings.

3. RESULTS AND DISCUSSION

3.1. Results on accuracy of cast end-frames

End-frames cast with commercial casting-jig

The measured dimensional results for end-frames cast with the commercial jig are summarized in Figure 14. The graphs represent the total expansion against the end-frame border width (T). A tolerance of 0.5 mm is considered acceptable and is indicated with a coloured band on the graphs.

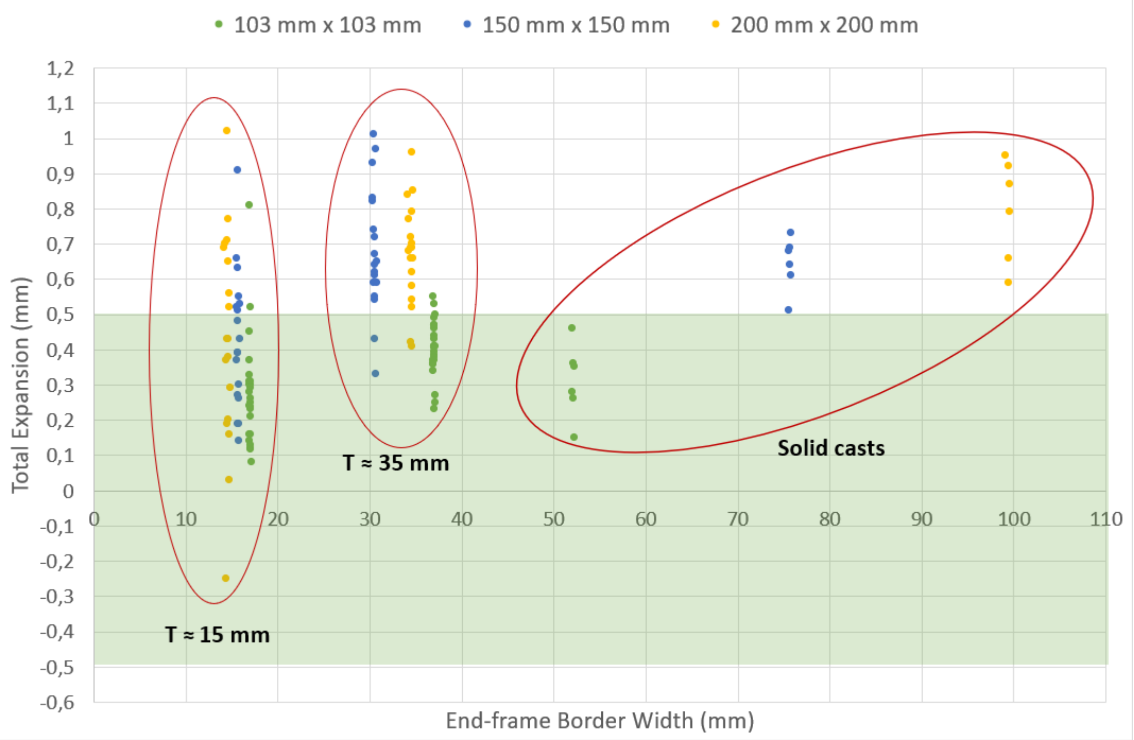


Figure 14: Total expansion of end-frames vs end-frame border width for three end-frames cast in the commercial jig, with T indicating border width of end-frames with portals

By comparing all the cast frame results of total expansion against the end-frames sizes in Figure 16 (commercial jig), it can be observed that the smaller (103 mm x 103 mm) end-frames expanded less than the bigger end-frames as the cluster of data points are closer to the acceptable range. This could be ascribed to the border width of the rubber jig, which is substantial and possibly limits further expansion. No expansion trend was observed as the frame sizes were increased.

No clear pattern could be identified to determine what the influence of the end-frames border width on the total expansion of the end-frames is. It is observed that the clusters of data points are spaced closer to the acceptable range with the thinner end-frames border width, but the solid cast does not expand considerably more compared to the frames with portals.

Further, it was observed that expansion-data point clusters of the solid castings increased almost linearly as the jig sizes increased. This was initially expected since there is more material expanding in the larger jigs as the alloy solidifies. However, the same conclusion cannot be drawn for the end-frames with portals. It was observed that the total point clusters were moving away from the acceptable range of the end-frames as the border width increased, but there is no clear pattern.

End-frames cast with optimised casting unit

The analysis of the graph results from Figure 15 shows that the total expansion of the end-frames cast with the optimised casting unit was within the acceptable range of 0.5 mm. However, there was still some expansion of the end-frames occurring, which could be ascribed to the quick-release clamps used to hold the corners of the frame together. The mechanisms of the clamps are spring-loaded and may account for some play if a force is applied by the expanding Wood’s alloy. The cluster of expansion-data points does not show a clear pattern to indicate an increase in end-frames sizes.

Figure 15: Total expansion of end-frames vs end-frames border width for three end-frames cast in the optimised casting unit with T indicating border width of end-frames with portals

There is no apparent increase in expansion associated with the increase in end-frames border width. However, the data point clusters can be seen to increase slightly with the increase in end-frames border width. Nevertheless, the solid casts do not expand considerably more than the frames with portals.

It is observed that expansion-data point clusters of the solid castings increase slightly, almost linear, as the jig sizes increase. This could be ascribed to the amount of alloy expanding while solidifying, placing more tension on the clamped corners. For the end-frames with portals, the total data point cluster seems to be moving upward, away from the original line, though there is no clear pattern.

3.2. Results on production time of end-frames

Figure 16 shows the summary of results where the optimised casting unit was cooled through water circulation and the commercial jig was allowed to air cool at room temperature.

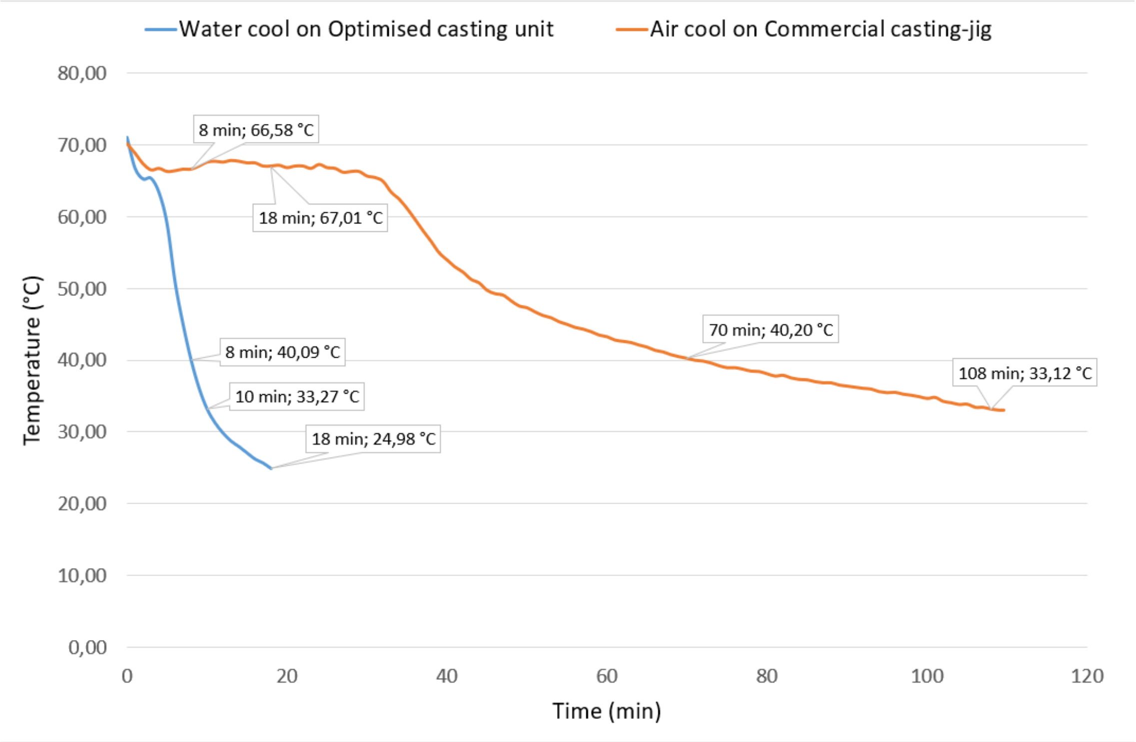


Figure 16: Cooling comparison between end-frames produced on commercial jig and optimised casting unit

The graphs clearly show that fast cooling on the new jig considerably reduces the casting time of the end-frames compared to the slow cooling on the commercial jig. Safe surface touch temperatures are below 44 °C (ASTM Committee, 1999), and the frames could be removed once this temperature was reached. Two callouts at 40 °C were added on the graph to indicate the time when the end-frame can be removed. The end-frames produced on the optimised casting unit can be removed after 8 minutes compared to 71 minutes without cooling for the commercial jig.

3.3. Results on density of cast end-frames

An initial visual inspection of the end-frames cast on the commercial Aktina Medical jig showed shallow cavities on the bottom surfaces. Some of the cavities inside the end-frames were also exposed during machining. The end-frames cast on the new jig with cooling showed no apparent cavities on the bottom surfaces, and no cavities were evident on the machined side of the end-frames.

Since hidden cavities may have formed inside the castings, this needed to be investigated. A means to determine this is to investigate how effectively the end-frames shield radiation. Radiation passing through areas of the end-frames would indicate lower density and thus porosity or cavities. The six end-frames were taken to the Oncology Department at the National Hospital, where they were tested on an Elekta SL25 LINAC. Gafchromic film was used for the experiment, which changes colour when exposed to ionizing radiation. The film does not require development, such as with conventional X-ray films. Photon energy of 15 Mega Volt (MV) was selected on the LINAC, and end-frames were irradiated for 1 000 Monitor Units (MU). The end-frames were exposed in sets of two, one slow-cooled and one fast-cooled (Figure 17 (a), (d), (g)), each set on a separate Gafchromic film. The fast-cooled end-frames are shown at the top of the images, and the slow cooled at the bottom. The photon radiation showed a pronounced discolouration of the film. All the films were scanned on an Epson desktop scanner set at 600 dpi. Due to the reflectiveness of the films, some light-coloured marks are visible on the images, which can be attributed to the scanning process (Figure 17 (b), (e), (h)). The photon-irradiated images were also processed to highlight changes in shielding ability (Figure 17 (c), (f), (i)).

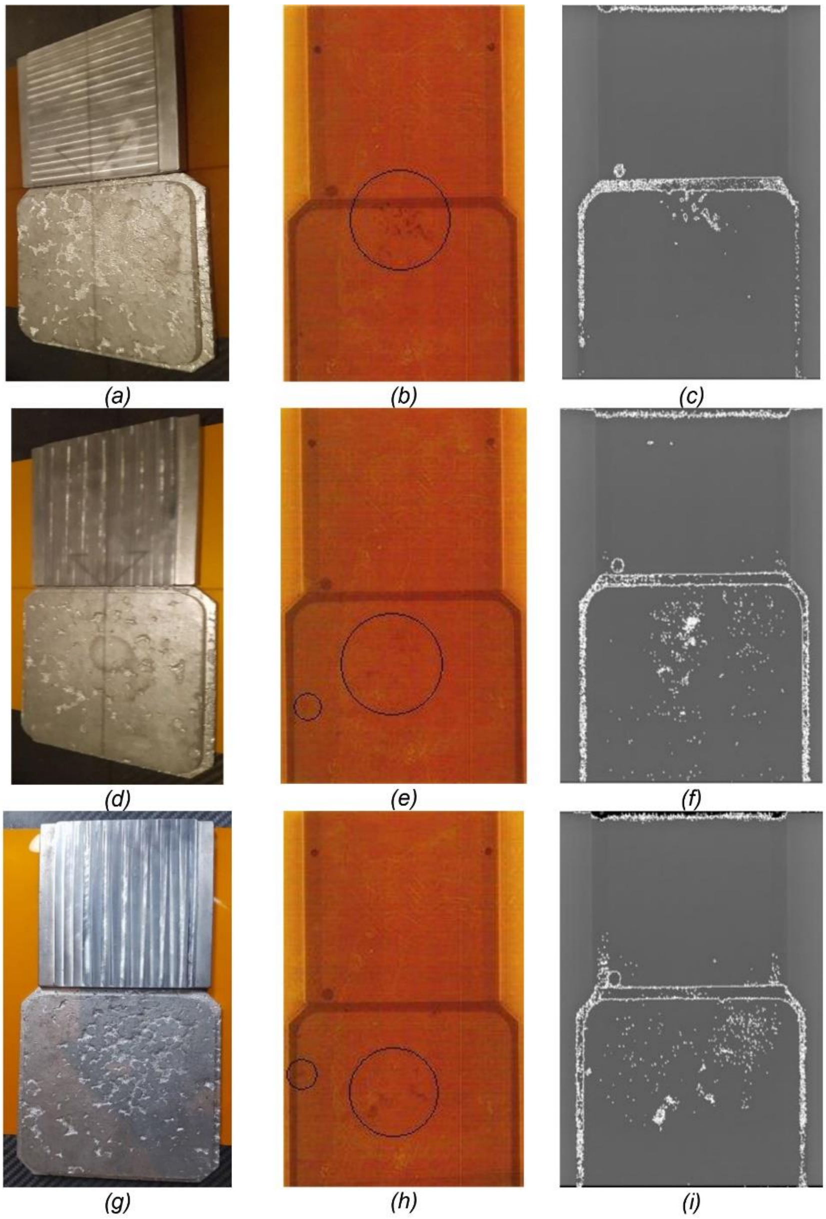


Figure 17: End-frames sets exposed with the corresponding Gafchromic film and processed image to highlight the difference in level of transmission

Each of the slow-cooled frames showed dark spots as highlighted by the circles in (Figure 17 (b), (e), (h)). This indicated higher radiation transmission than the rest of the frame and was also seen on the thinner edge of the slow-cooled frames and the binary and locating pins of the fast-cooled frames. The position of the cavities inside the end-frames is not the same for each end-frame, and there is no obvious way to tell if and where cavities will occur in the slow-cooled end-frames. The purpose of this experiment was not to quantify the amount of radiation that passes through the cavities in the end-frames but merely to indicate that there is uneven density across the slow-cooled end-frames which may result in radiation transmission.

4. CONCLUSION

The aim of this study was to develop equipment for casting Wood's alloy end-frames that are an improvement on end-frames that can be produced through commercially available equipment in terms of dimensional accuracy, density, production time, and cost. An optimised casting unit was developed, which incorporated the following features:

- Aluminium casting-frames that split across their diagonal corners developed for the optimised casting unit limit expansion of the Wood's alloy more effectively than the rubber-frames used in commercial casting-jigs. This was confirmed through dimensional measurement of produced end-frames.

- An optimised heating/cooling block was designed to ease the flow of the alloy while casting when the block is heated. Cooling the end-frames by passing cold water through the block reduces the production time of end-frames significantly compared to end-frames cast in a commercial jig that relies on heat exchange with ambient air for cooling. A time saving of 62 min was shown by measuring the time it takes for cast Wood's alloy to cool from a molten state to 40°C using the optimised casting unit compared to a commercial casting-jig. Even cooling of the block also ensures that no cavities form in the end-frame while the Wood's alloy solidifies. This was verified through Gafchromic films taken of the end-frames when exposed to photon irradiation on a LINAC.

- The new casting equipment includes all components required for casting end-frames in one convenient unit, including a heating/cooling block, a pot for melting the Wood's alloy, and an urn for heating the water. Provision made in the casting unit for the binary code and locating pins required for end-frames ensure that no additional machining is required to finish the castings.

A quotation obtained for a commercial end-frame casting-jig (R 26746.00) compared to the cost of having the new casting unit manufactured locally (R 30020.00) showed that the new casting unit will be slightly more expensive. The advantages that the new casting unit deliver should, however, be clear from the study.

Considering the benefits of the optimised casting unit compared to a commercial casting-jig described above, the aim of this study has been met. Radiotherapy departments will benefit from the availability of this equipment to produce end-frames with little effort, while patients affected by cancer will benefit from more effective radiation field shaping.

ETHICAL CLEARANCE

Although the equipment described in the article was developed for a clinical application, testing of the end-frames produced were not performed on humans or animals. Testing was limited to determining accuracy and density of the end-frames through measurements. Ethical clearance was therefore not required for the study.

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