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3D X-rays in footwear manufacture

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Digital imaging has removed the previously associated delay in processing X-ray images. This has opened the way for new imaging processes using X-ray images built up in real time into a digital composite image. For example, CAT or CT scanning, commonly used for medical examinations, uses images made up of hundreds of 2D X-rays to build up a virtual 3D image of the inside of a subject. New machines using this technology on a small scale (referred to as micro CT scanning) offer exciting potential for a number of industrial uses.

Conventional X-ray systems have drawbacks as only a 2D representation of a 3D item is acquired, not always rapidly and the view is usually limited

to a small part of the object being scanned. Micro CT scanning overcomes some of these drawbacks and offers many advantages over older X-ray systems, making a powerful diagnostic process available for use in quality control, fault analysis and product development, with useful applications for the footwear industry.

There are a number of techniques, such as scanning by laser or structured light, that offer the potential for the scanning of plastic and rubber components, where measuring dimensional stability and any change in volume after durability testing is of interest. SATRA has looked at different scanning and imaging solutions that could meet the needs of the footwear

industry in this regard.

For example, there is an ongoing need for metal detection in footwear, usually to check for the presence of tacks and other metallic items that might be accidentally left in the finished shoe. This detection may be in a single sample or across a batch of products. However, rather than just detecting the presence of metallic items in footwear, it is also often desirable to pinpoint their location and to visualise it. This is just one area in which micro CT can prove useful.

NEW X-RAY TECHNOLOGIES

Computed Tomography X-Ray inspection, sometimes referred to as CT, is a non-contact and non-

destructive method for obtaining internal and external information from objects ranging in size from microns to metres. It allows an operator to view and inspect the external and internal features of an object in a 3D space by taking hundreds or thousands of 2D digital X-ray pictures around an object as it is rotated on a sample holder. Software is then used to combine these 2D images into a viewable 3D shape which can be viewed on-screen and virtually 'sliced' through at any angle.

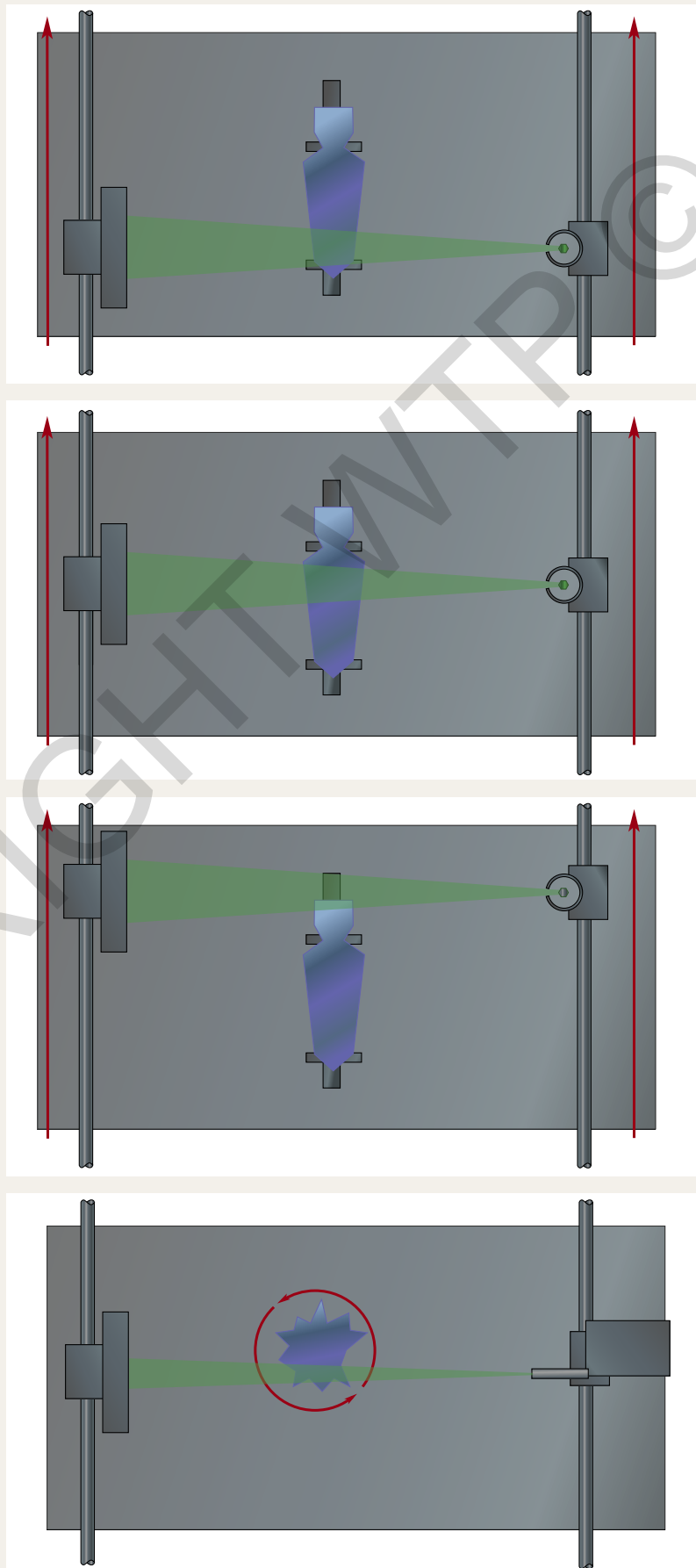
The usefulness of older X-ray systems was limited by factors such as the time it took to develop the film and to process any prints required after imaging. The advent of digital photography has launched the widespread use of Charge Coupled Devices (CCD) and other similar technologies, which are now routinely used to instantly create high resolution images that do away with the need for film and the associated delays. It has also enabled their use in CT scanning.

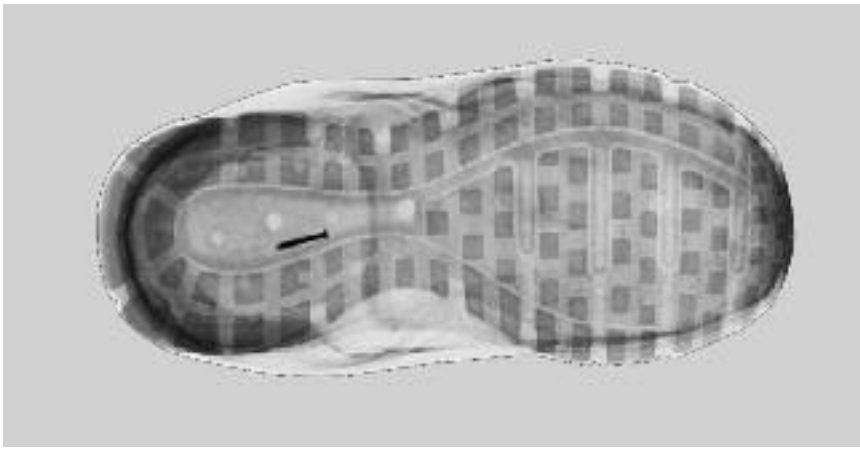
NON-DESTRUCTIVE TESTING (NDT)

SATRA tests a wide variety of products, not all of which can be assessed through destructive testing yet would benefit from an internal inspection: some because they are one-off prototypes, while others perhaps cannot be physically taken apart due to their material or construction. Examples include measuring wall thickness of sealed vessels, cracks or imperfection location in plastic components and checking for metallic items as previously mentioned. Micro CT scanning can address some or all of these issues.

For example, footwear containing shanks and penetration-resistant inserts can be checked to confirm their presence and location before and after testing to simulate wear. Conventional metal detection may confirm their presence, but 3D CT may be used to also show their actual location within the footwear and to check whether they have moved or deformed after testing. 3D CT also picks out differences in density, not just metallic items, so it will work with non-metallic components such as textile

How CT scanning works. The X-ray emitter is on the right, the sample in the centre and the detector on the left. The scan starts at the bottom and works upwards until the whole object has been covered. The final diagram represents a slice taken through the scanned sample.





An X-ray showing a shoe with a nail in it.

penetration-resistant inserts and wooden or plastic shanks, an advantage over conventional metal detection systems. This technology offers great potential for NDT assessments on a range of footwear products.

As an example of the kind of information available from micro CT 3D X-ray, a typical contract service from a company offering X-ray services may include image files constructed in 3D from 2D digital X-ray files, slice data in all three axes so a user can slide or scroll through the image a slice at a time, layer by layer and a video file showing rotation of the whole sample as well as a transition through its layers. Software sometimes included with the scan data gives the user the option to record his/her own movie files, which can be useful when presenting data to a third party.

As with other forms of digital imaging, a compromise must usually be reached between viewing a larger area at lower resolution or a smaller one at higher resolution. Larger objects can sometimes be scanned in multiple passes, building up more of the image with each pass.

MAKING SENSE OF DATA

A 3D X-ray image is usually scrutinised by altering the contrast through adjusting a histogram (an interactive graphical display related to the distribution of light and dark areas across an image) associated with the file, making 'shadow' or 'highlight' detail more or less visible. This tonal analysis has the effect of revealing or hiding areas of differing density across the sample, making, for example, either metal or rubber more or less visible. Voids or defects within a material, especially one that has been

moulded, can be made more obvious in this way as they become visible as areas of low (or no) density within an otherwise homogenous one. In addition, zooming in whilst selectively slicing through the sample, allows a user to concentrate on a single area and to perhaps highlight a fault in a specific part of the product under inspection and make corresponding assessments.

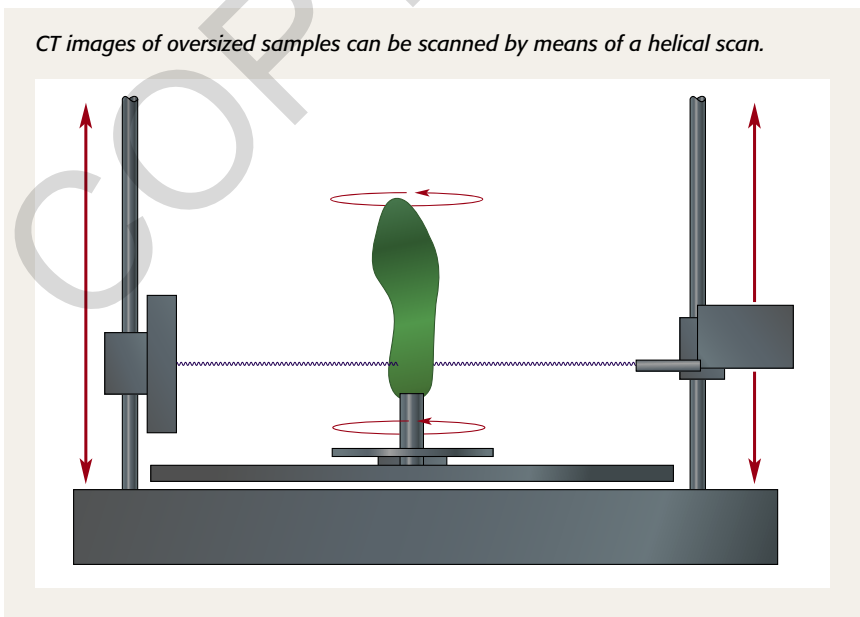
Machines capable of carrying out 3D CT represent a considerable investment, with some high-end machines incorporating additional features such as air conditioning introduced into the imaging area by means of an external control unit. This allows their use in specific metrology applications where images and measurements are to be taken under certain conditions of temperature and humidity. Digital X-ray machines require at least one dedicated computer workstation for image capture and processing, but extra PCs, servers and workstations can be added to speed up the work-flow or to handle specific memory-hungry applications such as Finite Element Analysis (FEA), a method of using numerical data (such as that contained in 3D data files) to predict how a product or material will react to real-world forces.

APPLICATIONS FOR NEW TECHNOLOGY

Another level of flexibility, resolution and quality, can be added to CT scans by carrying out X-ray scans in 4D, the fourth dimension being time. This is achieved by recording composite X-ray images of a product over a period of time, usually as some movement or change occurs within it. This kind of imaging has limitations, as samples must be entirely contained within the shielded area of the test machine, meaning that any power source that drives movement within the sample must also be housed within same area. If a footwear sample features moving parts that are not powered, these could however be moved by hand and then repositioned accordingly between images to create a 4D X-ray video.

This extra perspective opens up the use of micro CT for footwear applications such as assessing the

CT images of oversized samples can be scanned by means of a helical scan.



effectiveness of bladders, pumps and cooling systems that are designed to promote a cooling airflow around the foot during walking. In these instances, if a self-contained, perhaps battery-operated mechanism could be constructed that would cyclically apply a load to the pumping mechanism, then such a compressible bladder or pump could be examined dynamically by X-ray as the mechanism is activated. 4D X-ray might even be useful simply to show how cushioning and linings within footwear are compressed when a foot (in this case an artificial foot form) is inserted.

3D CT files can also be used as the starting point for further analysis techniques. They can be modified into a form useful for 3D modelling purposes or can be converted to 3D CAD or 3D printer files for output to 3D software packages. As mentioned, CT files can also be used for Finite Element Analysis for virtual testing and early prediction of structural or mechanical failures.

ASSESSING PRODUCT QUALITY

3D X-ray analysis can be useful not only for looking for unexpected items within footwear, but also for

confirming that it has been correctly made. Having recently reviewed a number of scans from some special insoles, an issue was noted resulting from the insufficient application of hot melt adhesive used to adhere some components at critical points. This insufficiency might have been observable by manually peeling apart the finished product, but doing so would have risked causing damage to the sample and masking or destroying evidence of the original problem.

As described earlier, successful use of the CT imaging technique involves the use of processing tools such as the tonal histogram to selectively highlight and view materials of differing density. However, even with judicious use, it is not always easy to pick out a material such as an adhesive which, in this instance, is transparent to X-rays, homogenous and present only in small amounts. Adding a chemical such as iodine or potassium iodate to such an adhesive before it is applied means that its presence (or otherwise) can be better detected in future scans. The use of 'tracer' chemicals in this manner can be another tool for successful product analysis provided they can be introduced into the product at the construction stage with the aim of facilitating future inspection and without affecting the function of the material.

A number of options exist for taking CT images of oversized samples. Particularly long or tall ones, for example, can be scanned by means of a helical scan. This involves rotating the sample holder through 360 degrees while the detector panel moves upwards relative to the position of the sample so creating a spiral path across it. Software then converts this spiral strip image into a full-volume one of the complete object. For other oversized samples that are too big to be scanned in a single pass there is the option of stitching together images from multiple scans where there is the space to take two or three full-detectors' width images in either the X or Y axis. Again, software can automatically join these images together.

Another extra capability presented is CT to Computer Aided Design (CAD)

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comparison. This involves X-raying a product and then comparing the 3D scan to the 3D CAD file used to control its manufacture. For instance, the X-ray scan of a last may be compared to the CAD file used to control the lathe on which the last was turned. Viewed in superimposition like this, any deviations or dimensional differences from the original design resulting from manufacturing issues or quality control become evident.

It is also possible to compare product against product in a similar manner as CT machines are well suited for batch assessments. Once suitable sample holders are in place and with saved parameters set on the machine, several samples can be scanned one after the other for quality control purposes with their scans overlaid or compared on-screen to look for any dimensional or structural differences between them.

ACCESS TO TECHNOLOGY

X-ray CT machines represent a considerable investment. However, for companies wanting their own facilities, there are a number of customisable machines available with options to suit the needs and budget of the user. There are no specific siting requirements for a 3D X-ray machine although consideration needs to be given primarily to its weight. Because of the lead and steel shielding required for its safe operation, a mid-level unit weighs around 6.5 tonnes, so obviously must be sited accordingly. High-end units have a number of extra features that might also have to be taken into account, such as an additional server and optional air-conditioning unit. Considerable floor space would need to be given over to such a machine with all of its fittings, but the increased capability for testing should ensure it is a cost-effective investment.

SUMMARY

3D CT technology could offer significant benefits to footwear manufacturers as well as distributors, importers and those concerned with quality control and materials analysis. A diagnostic tool like this can be invaluable for bespoke and non-standard assessment where a 3D

examination of a product before and after testing can provide information above and beyond pass/fail results, indicating why the product has passed or failed a particular test without having to resort to cutting it apart. Problems can sometimes arise when cutting or peeling a product apart to look for causes of failure and the inspection itself may well cause more problems than it detects. This is not an issue with CT scanning.

Micro CT brings enhanced capability to many areas of footwear manufacture and testing including scanning for all the factors described in this article and, potentially, many

more. While machines capable of Micro CT are not within all companies' financial reach, access to the technology via contractor services makes this technology available to all manufacturers, researchers and technicians needing to look more closely at the products in their field. The ability to see inside a product or material can be a powerful tool for anyone concerned with making better products. SATRA foresees 3D X-ray CT scanning being of particular interest to many involved in footwear manufacture and research, and expects to see increased use of this technology in the near future. 



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