Abstract
Magnetic Resonance Imaging (MRI) was employed for non-destructive identification of water distribution and moisture content in Wood Plastic Composites (WPC) exposed to exterior conditions. A WPC board exposed in Vancouver, BC for seven years was dedicated for the experiment and as a reference, a non-exposed WPC board was also tested. Using a Siemens MRI instrument, a variety of cross-section images of the board was obtained non-destructively by magnetic resonance imaging. The gray scales of these images were analyzed and verified by measuring the moisture content in selected board segments through oven drying. The experiments confirmed that MRI is an effective tool in the accurate and non-destructive identification of free water distribution (at concentration above 20%) in WPC.

Introduction
Evaluation of wood plastic composites (WPC) exposed in exterior conditions often requires monitoring of the moisture content (MC) and moisture distribution, which influence biological activity and mechanical properties. This process is conventionally performed by a destructive method by drying the sample at elevated temperature. In some situations, this is not a suitable approach. For example, a unique area of interest on a WPC sample needs to be monitored throughout the whole material, thus requiring a non-destructive method. For this reason the experiments with the MRI technique were conducted for the non-destructive analysis of moisture distribution in WPC. In this presentation, we demonstrate the use of MRI as a non-invasive method to analyze the MC and moisture distribution in WPC samples exposed to exterior conditions and subjected to biological activity from the natural exposure environment.

Magnetic Resonance Imaging (MRI)
The principle of MRI is similar to NMR (Hydrogen Nuclear Magnetic Resonance). The hydrogen nucleus (proton) has a non-null spin which causes it to align at a specific orientation under a strong magnetic field. A range of radio frequencies (RF) applied to these aligned protons could cause some of them to flip, causing some of the energy from the RF to be absorbed. The amount of energy absorbed at each frequency of RF depends on the electronic environment of the proton and this is what produces an NMR spectrum. In the case of MRI, the pulse of RF is applied to the subject within the strong magnetic field of the MRI magnetic coil. The instrument detects the amount of energy absorbed and the time it takes for the spin orientation to return in between pulses. The time frame of this process is commonly tuned for the detection of hydrogen in "free" water in which the hydrogens are attached to a mobile molecule. Hydrogens that are bound to an immobilized molecule are not detected. This means that water in wood bonded to the cellulose and lignin would not be detected by MRI. The magnetic field strength varies within the MRI chamber and the energy response of the hydrogen depends on the strength of the magnetic field. The coordinates of the hydrogen response can be determined to form a multi-dimensional image.

Objective
To determine free water distribution and moisture content in WPC using a non-destructive method such as Magnetic Resonance Imaging (MRI).

Experimental
A WPC board exposed for seven years at shallow conditions in Vancouver, BC was taken from the field in December 2011 for this experiment. The WPC board tested was extracted from a HDPE/pine wood blend in ratio 2.15/1 with the addition of small quantities of wax, lubricant and talc. The board surface was cleaned briefly and wrapped in plastic film to preclude moisture during transportation.

The cross sectional water distribution images of the board were obtained by MRI using a Siemens Magnetom Espree MRI instrument without damaging the board. Figure 1 illustrates the board of interest inside the MRI chamber. MRI images were taken from two different cross sections as A and B, as shown in Figure 2. A reference board stored in the laboratory with approximately 6% MC was also imaged by MRI in the same fashion.

This board was later cross-section destructively in three areas (1L, 2C and 3C) as indicated in Figure 3 to obtain the moisture content using the conventional method. Block 1L was taken parallel to the board ends and blocks 2C and 3C were taken parallel to the top surface. Each block was cut and sanded approximately 1 mm thick and with similar cerf. Water specimens were then dried to constant weight (approximately 48 hours) at 105°C in an air forced oven and the moisture content for each specimen was calculated knowing that the wood content in the board was 65%.

The multiple MRI images of the cross-sections of interest were averaged using Image Pro Express software to obtain a single cross sectional image that was more representative to the area of interest and returned undamaged for further exposure. The vicinity of the upper surface at a distance of 6.1 mm from the surface • The vicinity of the lower surface at a distance of 3.2 mm from the surface • At the end of the board at 11.2 mm from the board end • board contact with supporting Z12™ beam at the width of 64mm and depth exceeding 1/2 of the board thickness

Results and Observations
An MRI image of cross-section A, parallel to the end of the board, 2 mm from the board’s end is shown in Figure 4. An MRI image of cross-section B parallel to the board length in the centre is shown in Figure 5.

- The MRI images of cross-section B (Figure 5) showed four areas in the tested board with a significant increase in moisture content:
  • The vicinity of the upper surface at a distance of 6.1 mm from the surface
  • The vicinity of the lower surface at a distance of 3.2 mm from the surface
  • At the end of the board at 11.2 mm from the board end
  • board contact with supporting Z12™ beam at the width of 64mm and depth exceeding 1/2 of the board thickness

A reference sample with around 6% MC was completely invisible in the image. MC data from destructive testing of the area of interest, 1L, 2C and 3C are shown in Figures 6a, 7a and 8a, respectively. The corresponding averaged MRI cross sectional images are shown in Figures 6b, 7b and 8b, respectively, with the same spatial scale as the plots.

- The MRI image started to show shades of grey in areas with 20% or higher MC.
- The image is saturated in white in areas where MC is above approximately 25%-30%.

The cross sectional water distribution images of the board were obtained by MRI using a Siemens Magnetom Espree MRI instrument without damaging the board. Figure 1 illustrates the board of interest inside the MRI chamber. MRI images were taken from two different cross sections as A and B, as shown in Figure 2.

Figure 2: Exposure of the WPC board examined by MRI. MRI images were taken in the cross-section parallel to the lines indicating cross section A and B. Please note the biological activity visible in the vicinity of the upper surface which indicate the liquid water concentration in the sample. Water below the fibre separation point (3C) during exposure. Please note that the photo shows the back side (unexposed side) of the board which has a dark green discolouration. The cross section corresponds to the end of the board (1L), center of the board (2C) and the area of board support (3C) as shown in Figure 3a.

Figure 3: Sections used for MC evaluation are indicated in the photo of the evaluated WPC board. These sections correspond to the end of the board (1L), center of the board (2C) and the area of board support (3C) as shown in Figure 3a.

Figures 6b, 7b and 8b: The MRI images of cross-section B (Figure 5) showed four areas in the tested board with a significant increase in moisture content:

- The vicinity of the upper surface at a distance of 6.1 mm from the surface
- The vicinity of the lower surface at a distance of 3.2 mm from the surface
- At the end of the board at 11.2 mm from the board end
- Board contact with supporting Z12™ beam at the width of 64mm and depth exceeding 1/2 of the board thickness

A reference sample with around 6% MC was completely invisible in the image. MC data from destructive testing of the area of interest, 1L, 2C and 3C are shown in Figures 6a, 7a and 8a, respectively. The corresponding averaged MRI cross sectional images are shown in Figures 6b, 7b and 8b, respectively, with the same spatial scale as the plots.

- The MRI image started to show shades of grey in areas with 20% or higher MC.
- The image is saturated in white in areas where MC is above approximately 25%-30%.

- There is a good correlation between the gray scale of the MRI image and the moisture content in the wood of the WPC board tested by drying the waters cut from samples. The black colour starts to turn into dark grey at about 20% MC approaching fiber saturation point. The light gray turned to white at approximately 25%-30% MC.

- As indicated by MRI imaging, the wood plastic composite board exposed in Vancouver for seven years showed increased water absorption at the board end and support area. In particular, the support area showed a significant increase in MC in the bottom section up to half of the board thickness. Increased MC at the board end was seen up to 16 mm from the cut.

Comments and Conclusions
• MRI is capable of detecting water near and above the fiber saturation point and its distribution in WPC, with images turning from black (dry region) to white (wet region) as the plots.

- MRI has been used to assess the state of wood plastic composites, which have been exposed to exterior conditions.

- The MRI images can provide information about the moisture content and distribution in WPC, which can be used to assess the durability of the material under exterior conditions.

- The results obtained from MRI images are consistent with those obtained from destructive testing, indicating the potential of MRI as a non-destructive method for assessing the moisture content and distribution in WPC.