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Impact response of polymeric train sleepers

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Abstract: The impact response of railway sleepers made of high-density polyethylene and Glass Fiber Reinforced Polypropylene Compound was accessed via transverse impact tests using a drop hammer facility. The sleepers were subjected also to a wide range of temperatures, including extreme negative ones. The impact was properly monitored so information, like load profile, was accessed. The results can be used for finite element analyses purposes so the design of polymeric sleepers can be performed and improved as an alternative for traditional materials like wood and concrete.

Keywords: Railway sleeper, Polymeric composites, Impact Test, low temperature.

INTRODUCTION

Railway sleepers keep the rail tracks in their position and transfer the train and cargo weight to the ballast bed (Raj, Nagarajan, and Shashikala 2021; Remennikov and Kaewunruen 2008). The sleepers are traditionally manufactured of timber, prestressed concrete, and steel. The wide variety of materials emphasizes that none of the above-mentioned materials is the best option, i.e besides their suitable advantages each has some disadvantages, thus the railway industry is seeking new materials to improve the railway transportation quality (Ferdous et al. 2015).

These days composite sleepers have emerged as the substitute for timber sleepers (ERP and MCKAY 2013). Composite materials offer several excellent properties such as high strength (stiffness) to weight ratios, and good resistance against corrosion, moisture, and insects (Ferdous et al. 2015). However, the application of composite sleepers is extremely limited (Camille et al. 2022; ERP and MCKAY 2013; Ferdous et al. 2015). The design and production cost of the composite parts has been the main barrier to the wide usage of composite materials in many industries like aerospace, automotive, and railway. However, developing reliable finite element codes and less expensive manufacturing processes is making composite material more competitive with the traditional materials, since today more than 50 % of the structural weight of new passenger airplanes like the Boeing 787 Dreamliner and Airbus A350 are made of composite materials. Thus composite sleepers also could gain more attention in the future.

Besides the price, composite sleepers are somewhat new with unknown in-situ and long-term performance (Camille et al. 2022), and their impact response strain rate sensitivity, and effect of different environment temperatures on mechanical properties of polymer composites sleepers have been less investigated yet.

A railway sleeper is likely to experience impact loading that lasts for a fraction of a second. The magnitude of the loads is very higher than quasi-static loads within a very short impulse duration (2–10 ms) (Remennikov and Kaewunruen 2008) (Ferdous et al. 2015; Ngamkhanong and Kaewunruen 2020). The effects of impact loads are critical issues in the design process of sleepers in railway systems. The wheel/rail abnormalities, such as wheel flat or dipped rail, could produce impact loads that will transmit to the sleepers. Moreover, a direct impact between wheels and sleepers during derailments (Koller 2015) could produce significant impact loads and consequential damages to the sleepers.

A comprehensive review of studies that have considered dynamic impact loads in the railway system is provided in Ref (Remennikov and Kaewunruen 2008). The dynamic effects of rail/wheel abnormalities like rail corrugation, wheel flats, and shells, worn wheel and rail profiles, bad welds or joints, and track imperfections, are classified based on the time duration, magnitude, and shape of impact loads. It is concluded that the typical magnitude of the above-mentioned abnormalities is between 100 kN to 750 kN which is a function of train speed. The duration of these impact loads varies between 1 to 12 ms (Remennikov and Kaewunruen 2008).

The drop hammer rigs have been widely utilized to investigate the impact response of railway sleepers (Camille et al. 2022; Dukkipati and Dong 1999; Ferdous et al. 2015; Hameed and Shashikala 2016; Kaewunruen and Remennikov 2011; Koller 2015). The test set-ups are quite similar, a body mass so-called impactor with a specific mass dropped from a height on the sleeper, to investigate derailment (Koller 2015), or on the assembly of rail track and sleeper (Camille et al. 2022). Based on available data in the literature, the average weight of the impactors is approximately 500 kg and the average drop height has been considered equal to 750 mm above the specimens (impact energy equal to 3.6 kJ). Most of the above-mentioned investigations have considered prestressed concrete sleepers under impact load.

The effect of reinforcing concrete sleepers with macro synthetic fiber under impact loading conditions was investigated using a drop hammer rig in Ref. (Camille et al. 2022). The impactor having a 52 kg mass was dropped from 1000 mm height on the rail track and prestressed concrete once. This impact scenario led to impact forces that lasted about 10 ms and had peak loads around 700 kN. A minimal effect of fibers on the impact force has been reported in this study. It is concluded that it is necessary to develop numerical models for impact simulation to understand the impact behavior of sleepers in a less expensive manner rather than through experimental procedures.

Although several polymeric composite sleepers have been developed and utilized in several countries, impact test results on these relatively new sleepers are rarely available in the open literature (Ferdous et al. 2015). For example, in Ref. (Koller 2015) the impact results of the FFU synthetic sleeper, developed by Sekisui Chemical Co. Ltd. in Japan, are presented. In this study, a body with a mass of 500 kg and a cutting edge shaped like a wheel flange is dropped from a height of 75 cm twice for each test and lands on the edge of a sleeper inclined at 30° (Koller 2015).

Finite element models of impact on the assembly of rail tracks and sleepers have been developed, for instance, the Ls-Dynal model of impact presented in Ref. (Ngamkhanong and Kaewunruen 2020). However, experimental drop hammer tests are required to validate the finite element models.

The present study aims to investigate the impact response of a polymeric composite rail sleeper developed by Braskem company under different impact energies. Since it was observed that environment temperature will change the mechanical properties of the polymeric composite material of the sleeper, the effects of extremely low temperature on the impact response of the sleepers were investigated and compared to the results of impact tests at room temperature. The results could be useful to develop reliable FE models of polymeric sleepers under dynamic loadings.

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EXPERIMENTAL IMPACT TEST DESCRIPTION

The impact investigation was conducted using a drop hammer test facility at the University of Sao Paulo, GMSIE laboratory, Fig. 1 shows the schematic presentation of the drop hammer rig. The impactor (striker) of the drop hammer has a maximum capacity of 1000 kg and 10-meter height above the anvil. The drop hammer test can be equipped with several measuring and imaging devices like high-speed cameras, laser velocimeter, accelerometers, and load cells.

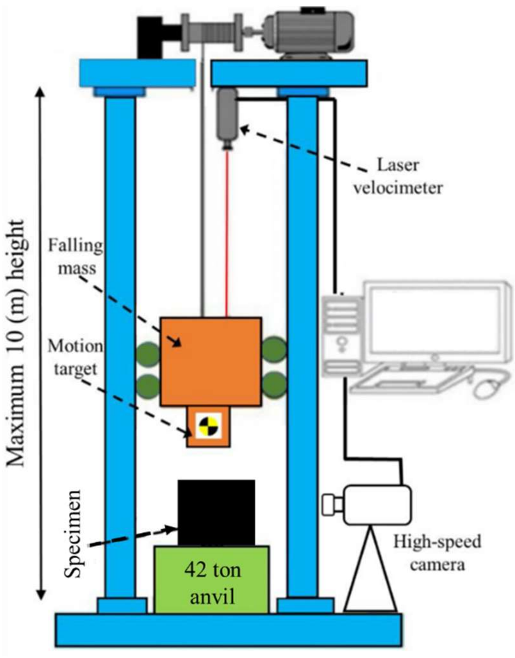
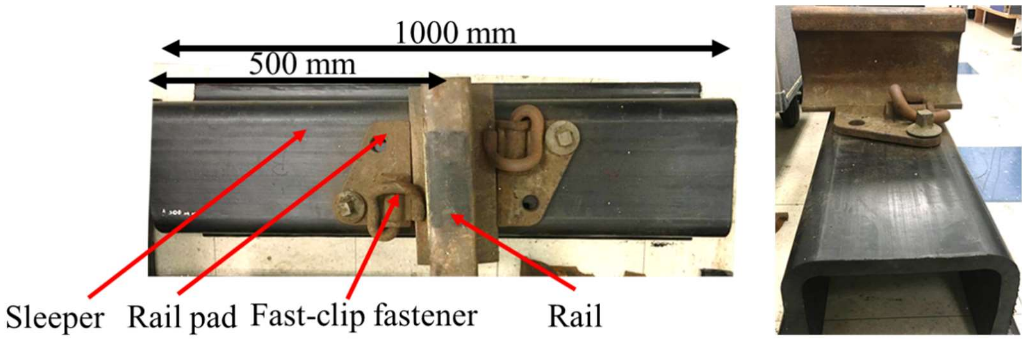


Figure 1 - Schematic of Drop hammer facility at GMSIE laboratory.

Impact tests were conducted on the assembly of rail, rail-pad, fast-clip fasteners, and composite sleeper, as illustrated in Fig. 2(a). The composite sleepers consist of two parts; (i) glass fiber-reinforced composite part (the U-shape) and (ii) block of HDPE, see Fig. 2(b). The length of the U-shape part is 1000 mm and the HDPE block having 600 mm length is placed in the middle of the U-shape part. However, before testing 150 mm of U-shape part's ends was trimmed to facilitate the handling of specimens and due to the size of the thermal chamber.



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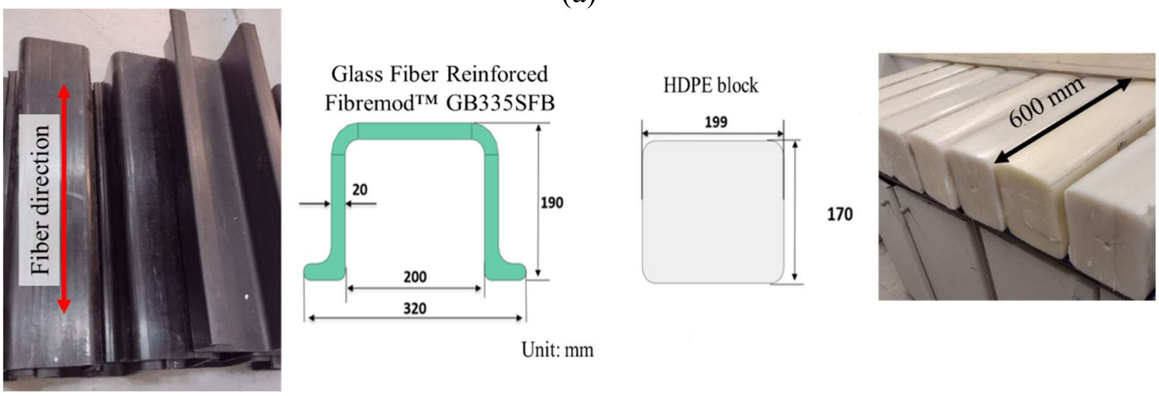
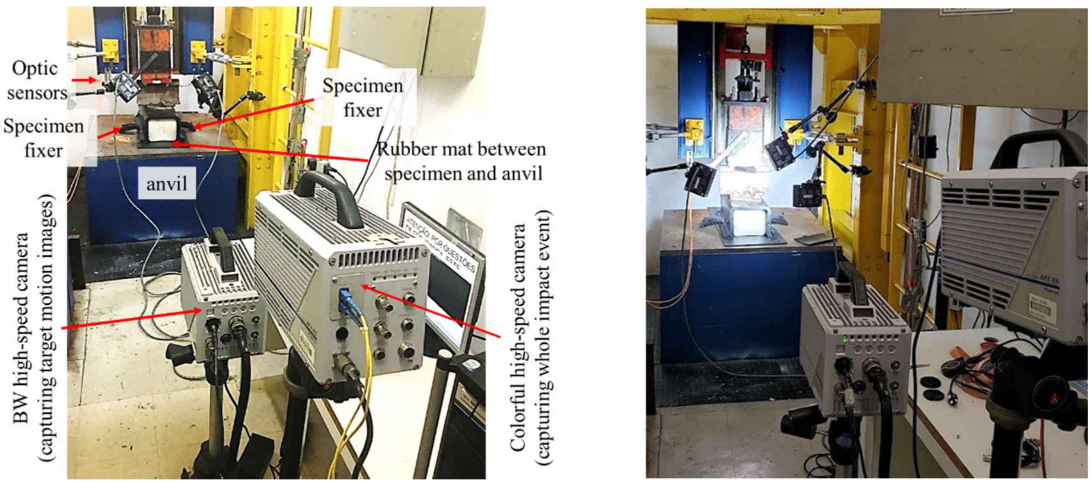


(b)

Figure 2 - Assembly of railway track and composite sleeper; (a) The assembly of rail track and sleeper, (b) The sleeper's parts.

Figure 3 shows the impact set-up that was equipped with high-speed cameras, LED illuminations, and optic sensors. Two high-speed cameras were used to record the impact event. Fastcam SA5 high-speed camera with 230 kfps was used to tract the motion target to find displacement, velocity, and acceleration of the impactor during an impact event via digital image correlation. This recording speed (230kfps) is equivalent to a 230 kHz sampling rate which is quite enough for the present low-velocity impact study. A colorful high-speed camera with (3) three kfps was used to capture the whole impact event on the sleepers see fig.3.



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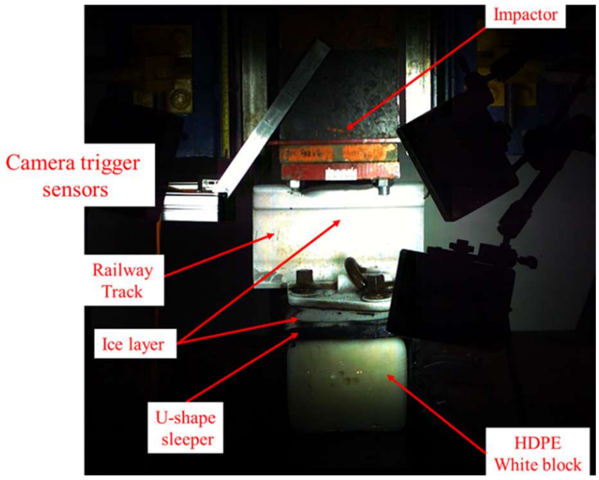

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Figure 3 - Impact set-up; (a) General overview, (b) Zoom-in view of the real test.

The specimen was placed on the anvil of the drop hammer then it was positioned so that the impactor hits the rail track symmetrically. A soft rubber mat having 8 mm thickness, provided by Braskem, was placed between the sleepers and the rigid face of the anvil (under sleeper pads (USP), as shown in Figs. 3 and 4. The sleeper motion was restrained is some points to prevent any bounce back and tacking off the specimens from the anvil during the test. Two clamps compress the edges of sleepers towards the anvil as shown in Fig. 4(a). Although these clamps restrict the vertical movement of the sleepers, however, most parts of the sleeper (U-shape part) could deform freely, Fig. 5 shows the deformation of the sleeper under impact.

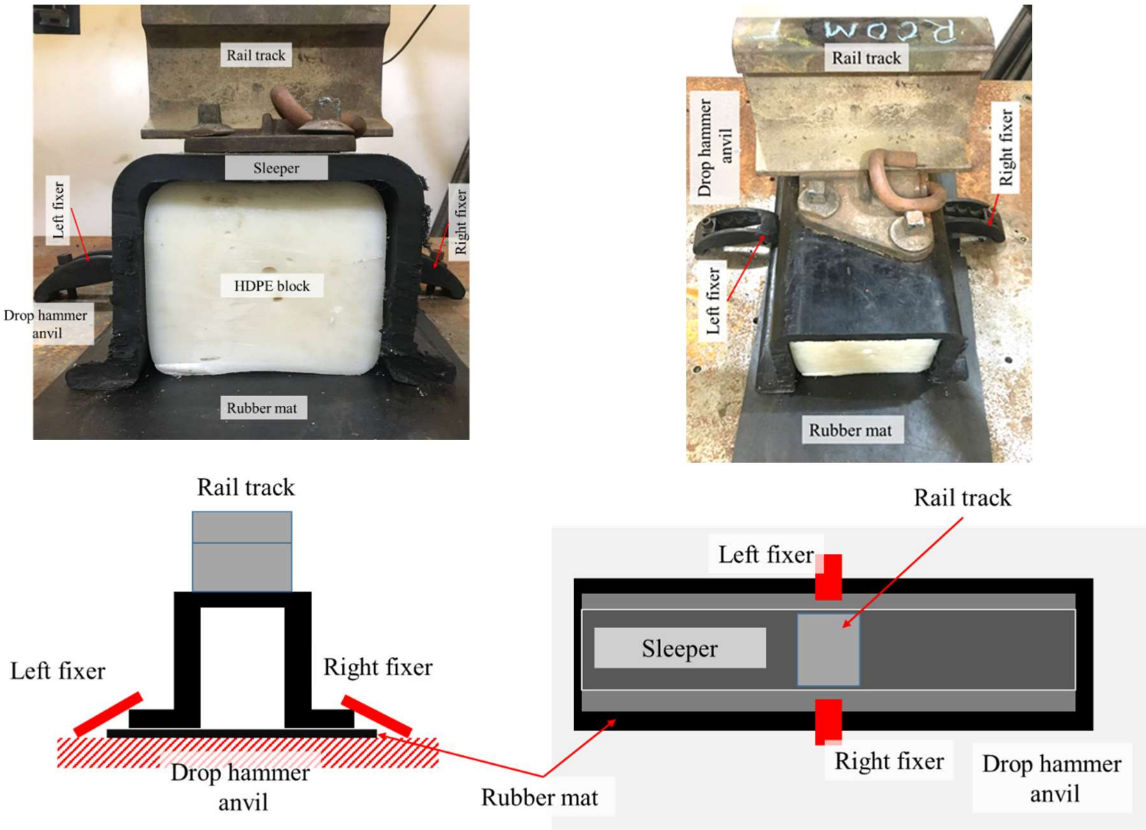


Figure 4 - Boundary condition of the sleeper.

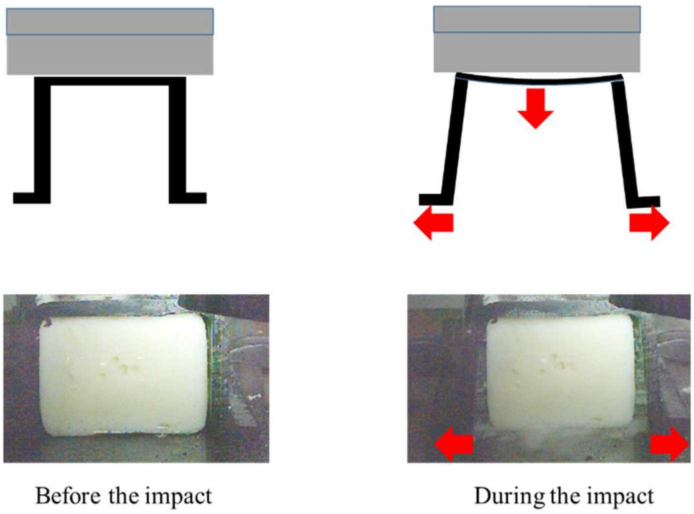
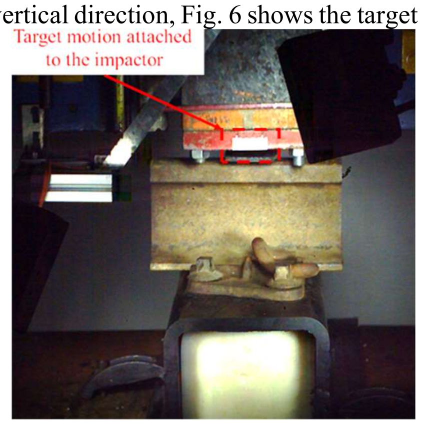


Figure 5 - Schematic and real presentations of deformation of sleeper under impact load.

Impact tests were conducted at room temperature (~25°C) and low temperature (~-30°C). The assembly of the rail track and sleeper had been placed in a thermal chamber for a few hours to reach an acceptable thermal equilibrium. The specimens were placed in the thermal chamber where clod air was circulating over the specimen. Thermal chamber equipped with DC fans that blow air over buckets of dry ice (temperature of dry ice at surface is about -78 °C). After a while, the air inside the thermal chamber reaches an extremely low and constant temperature. Then the specimen was kept for several more hours at this low temperature. Finite element analysis was used to find minimum exposure time to have approximately uniform low temperatures in all parts of the specimens.

Gom correlation software was used to analyze high-speed camera images to find, the displacement, velocity, and acceleration of the impactor in the vertical direction, Fig. 6 shows the target motion and digital image correlation software.



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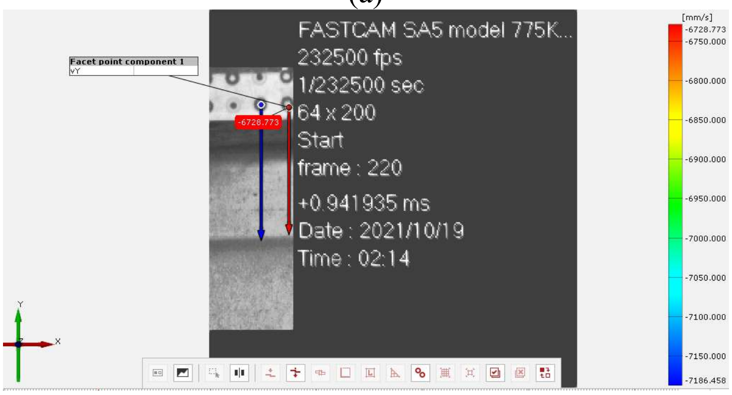


(b)

Figure 6 - Captured images with high-speed cameras during the impact test; (a) The targe motion stickers, (b) Tracking motion target stickers using Gom correlation software.

The specimens were impacted with an impactor with constant mass (130 kg) and different initial velocities (different kinetic energies). The impactor is dropped repeatedly over the specimen and the height of the impactor increases after each impact for the next repeat. For each specimen testing procedure started with the lowest impact energy (impactor dropped from 1 (m) height above the specimens, impact energy equals 1.27 kJ), then after impact visual inspection was done to detect visible damage and failure. If no damage was detected the specimen was impacted again with higher kinetic energy. This procedure had been repeated until damage and failure were detected in the specimens. Fig. 7 shows the testing procedure.

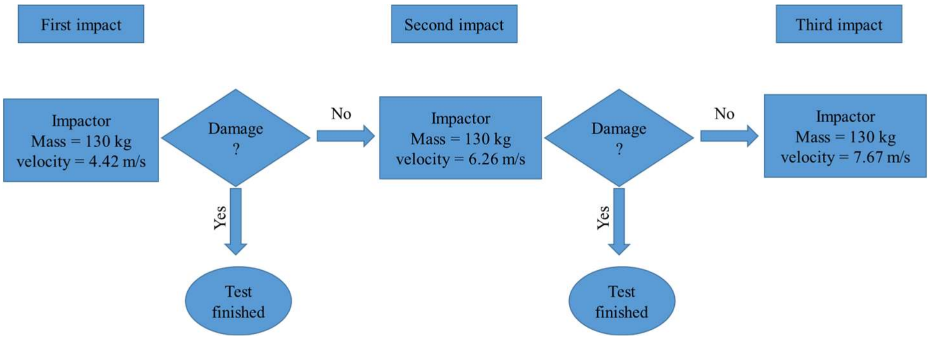


Figure 7 - Impact test procedure.

RESULTS AND DISCUSSION

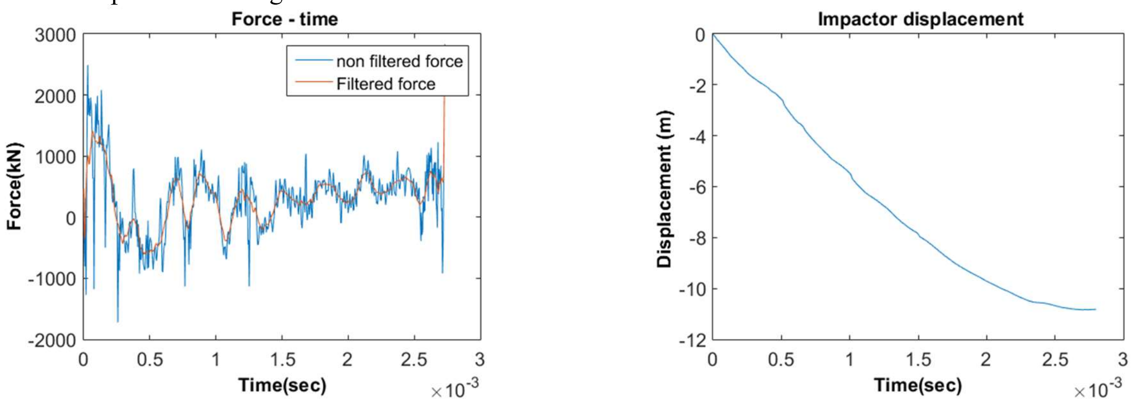
The force-time histories of impact tests on the specimens are presented in this section. Moreover, the velocity and displacement of the impactor during impact tests were plotted against time. A coding system to name the specimens under different conditions was conceived. The codes and definitions are listed in Table 1. Here only results for the highest impact energy at cold and room temperatures are presented.

Table 1 - Specimen coding system.

Specimen code	Testing condition	Drop height of the impactor (m)
IL1	Low temperature	1
IL2	Low temperature	2
IL3	Low temperature	3
IR1	Room temperature	1
IR3	Room temperature	3

Results of impact test on specimen IL3

The results of the impact test on the sleeper at low temperature while the impactor dropped from 3 (m) height above the specimen are presented in Fig. 8.



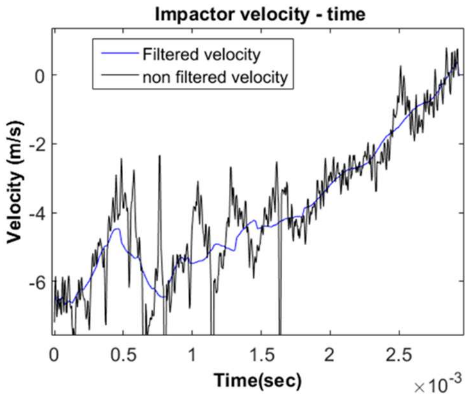


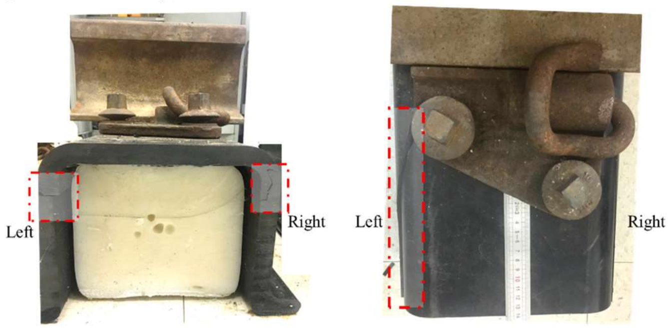
Figure 8 - Impact force on the specimen, displacement, and velocity of the impactor during the impact event; Test @ low temperature and the impactor dropped from 3 (m) height above the specimen.

Table 2 lists some features of the impact test on the IL3 specimens. It is worth noting that displacement of the impactor is equal to permanent, elastic deformation of the specimen and the rubber mat between the anvil and sleeper.

Table 2 - Impact test results; Specimen IL3.

The maximum displacement of the impactor (mm)	11.1
Average force (kN)	350
Peak force (kN)	1950
Impact energy (kJ)	3.82
Visible damage	Observed

For all specimens, post-impact visual inspection was conducted to detect any damage and failure in the sleepers. Fig. 9 shows the damages observed on the U-shaped part of the sleeper IL3 specimen (test @ low temperature and the impactor dropped from 3 (m) height above the specimen).



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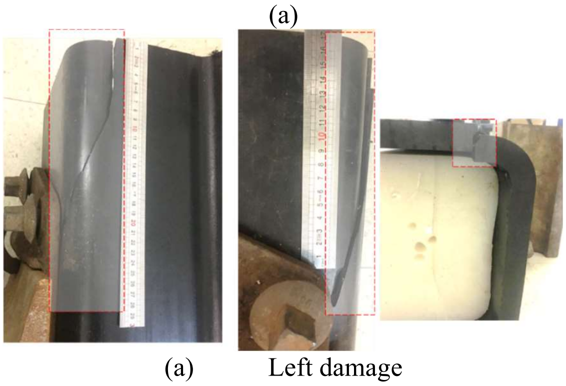


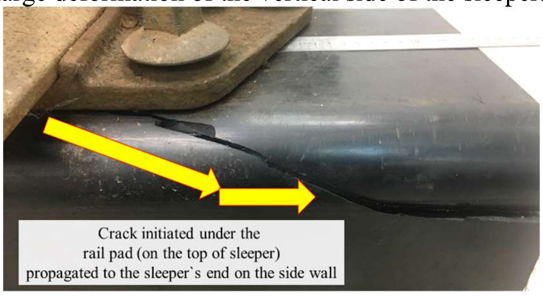
(a) Left damage

(b) right damage

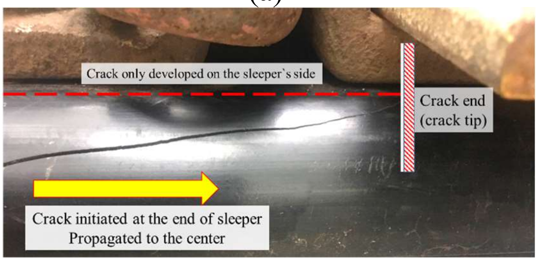
Figure 9 - Detected damage and failure in the sleeper after impact; Specimen IL3.

Figure 10 shows the damage initiation and propagation directions on the IL3 specimens. Crack on the left side initiated under the rail pad on the horizontal region of the U-shape sleeper. Then the crack developed on the vertical side of the sleeper and ended up on the end of the sleeper (see Fig. 10(a)). Both cracks on the right and left of the sleeper developed only in one direction to the end of the sleeper, however, the right side cracks initiated on the vertical side (end of the sleeper) and developed to the center of the sleeper. The crack on the right side did not reach the horizontal part of the sleeper (see Fig. 10(b)).

The crack on the left was initiated due to the high-stress condition under the rail and rail pad, however, the crack on the right was initiated due to large deformation of the vertical side of the sleeper.



(a)

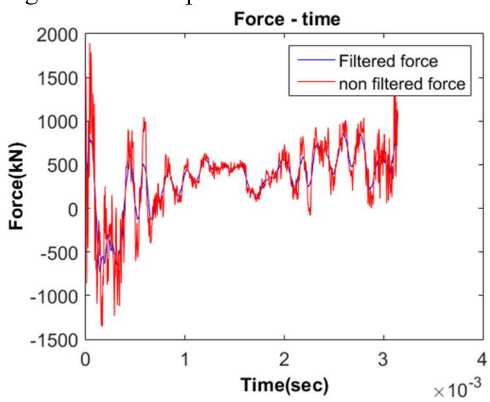


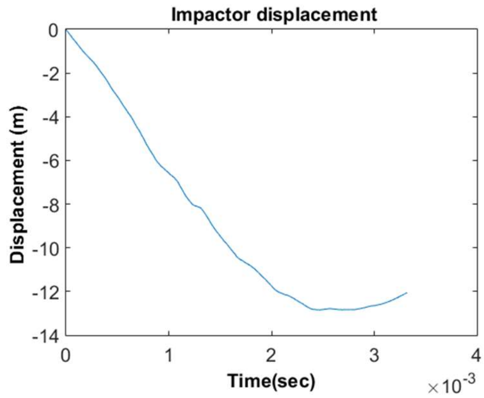
(b)

Figure 10 - Crack location, initiation, and propagation on the U-shaped sleeper part; (a) Left side, (b) Right side; Specimen IL3.

Results of impact test on specimen IR3

Figure 11 shows the results of the impact on the sleeper at room temperature while the impactor was released from a 3 (m) height above the specimen.





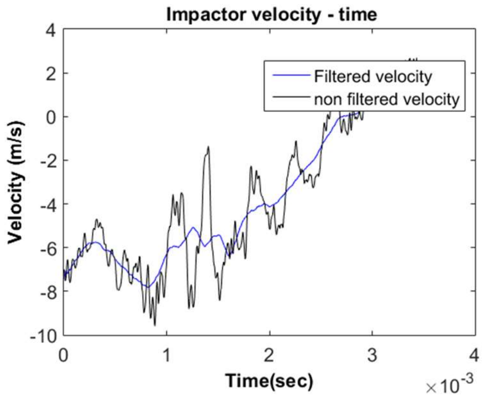


Figure 11 - Force and velocity of impactor during the impact event; Specimen IR3.

Table 3 lists some features of the impact test on the IR3 specimens. It is worth noting that displacement of the impactor is equal to permanent, elastic deformation of the specimen and the rubber mat between the anvil and sleeper.

Table 3 - Impact test results; Specimen IR3.

The maximum displacement of the impactor (mm)	12.1
Average force (kN)	361
Peak force (kN)	1860
Impact energy kJ	3.82
Visible damage	Not observed

Comparison between specimens

The typical impact force history for all specimens (assembly of the rail and sleeper) can be divided into 3 stages; in the first stage impact force increase rapidly and reach its maximum value, then the impact force decreases dramatically (Stage II). During the third stage, the impact force oscillates around the average force. The typical impact force on the specimens is presented in Fig. 12.

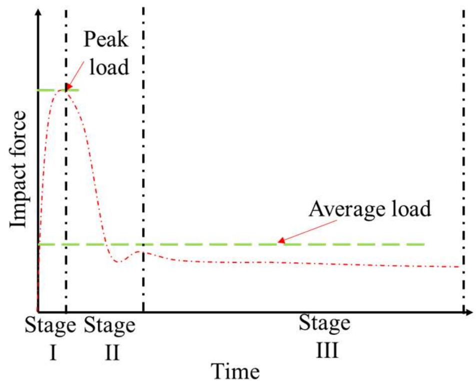


Fig. 12. Typical impact force history of all specimens in this study.

Figure 13 compares the maximum deformation of the vertical sides of the U-shape part of IR3 and IL3 specimens. Since both specimens were impacted by the same kinetic energy, low temperature could be the main reason that the IL3 specimen failed under impact loading.

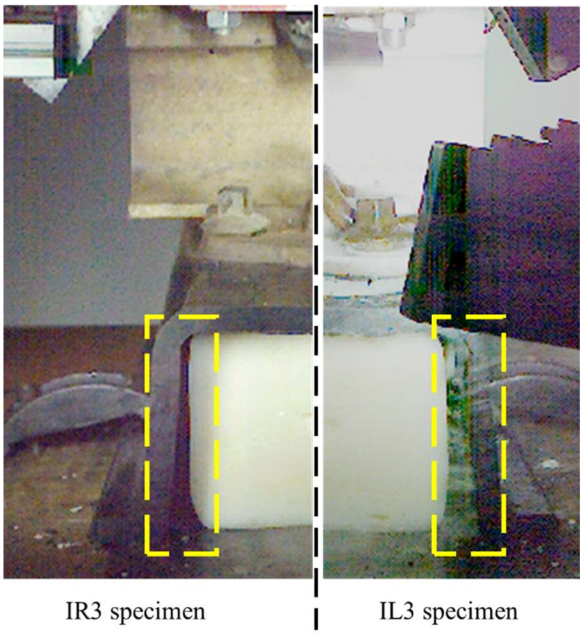


Figure 13 - Temperature effect on the deformation of specimens under the highest impact energy in this study.

In contrast to obvious damage to the IL3 specimen, it seems that low temperature did not have a significant effect on the impact forces of IR3 and IL3 specimens as shown in Fig. 14. This issue could emphasize that the main load-bearing part of the sleepers is the HDPE block.

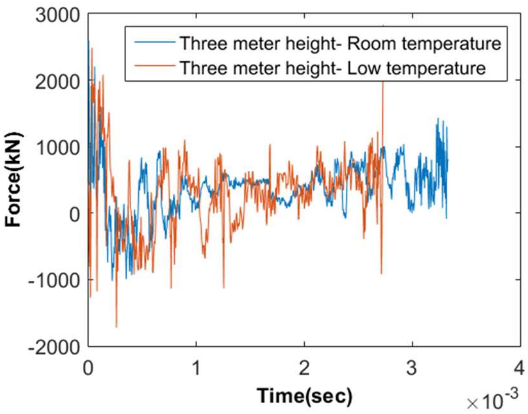


Figure 14- Effect of temperature on the impact forces.

CONCLUSIONS

The impact response of polymetric railway sleepers was investigated experimentally. The sleepers are developed by the Braskem company and are being installed in Brazil. Since the material of these sleepers are polymeric composites the effect of loading rate and temperature could significantly affect the mechanical properties of these materials. The low-temperature impact test has been performed to check the temperature effect on the impact response of these polymeric composites. Also, different impact velocities were considered to check the effect of loading rate.

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