# Glulam Wood Sleepers Manufacturing from Recycling Discharge Sleepers: An Engineering Recycling Project

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Feasibility was studied for the manufacture of glulam sleepers using wood sleepers that had been discharged or sold at low prices by railway companies. In principle, an engineering recycling project of this nature could contribute to the reduction of non-renewable natural resource extraction. The manufacturing stages of glulam recycled wood sleepers are shown. Ultrasonic tests were used for the classification of the wood sleepers' parts and wood strength optimization. The results showed that it was possible to obtain one wood sleeper from the recycling of four or five used sleepers.

*Keywords: Wood recycling; Glulam wood sleepers; Sustainability*

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## INTRODUCTION

The sleeper is a superstructure element installed across train rails that receives and transmits vehicle load stress to the lower structural elements (Brina 1979). The sleepers partially dampen vibrations and provide support and fixation of the rails, keeping the distance between them stable, that is to maintain the gauge width. Also, these structural elements are subjected to simultaneous shear and bending stresses, and thus they are also extremely important.

The demand for wood sleepers in the Brazilian railways is about 1,500,000 a year, according to the largest Brazilian railway company (Latin America Logistics, LAL). This information is for the three railroads that ALL company manages (Passos 2006).

Wood was the first material to be used to construct sleepers, and 2.5 billion wooden sleepers have been installed worldwide (Ets Rothlisberger 2007). The four countries with the largest rail networks are the U.S., Russia, China, and India (CIA 2013). Brazil occupies the tenth position in this ranking and 17$^{th}$ place when comparing railway densities (Icimoto 2013). The Brazilian rail network stretches over 30,402 kilometers (ANTF 2015).

The wood used in Brazil for manufacturing sleepers are noble timber species such as maçaranduba (*Manilkara huberi*), aroeira (*Astronium lecointei* Ducke), and ipe (*Tabebuia serratifolia*) from native forests (Passos 2006; Icimoto 2013). Because of their scarcity and the environmental impacts of harvesting these species, reforestation woods have been studied, tested, and used in the manufacture of wood sleepers (Da Rocha 2003; Icimoto 2013). Da Rocha (2003) evaluated the resistance of native and reforestation timber through non-destructive testing to explore their use alternatives to hardwoods in railroad sleepers.

Other materials such as concrete, steel, polymers, and composite materials are being used as an alternative to wood sleepers (Werner and Schrägle 2008). Washid *et al.* (2015) presented a brief review on sleepers, including the different types of materials and composite materials used to manufacture them.

Heebink *et al.* (1977), Geimer (1982) and Carrasco *et al.* (2012) studied the reuse and recycling of wood sleepers for the manufacturing of new ones. They studied laminated particle sleepers made from discharged sleepers that were ground into small flakes of 0.508 mm thickness and 50.8 mm length. These surveys were motivated by the high demand for timber sleepers for American railroads and contributing to environmental preservation by avoiding the burning and discharging of wood sleepers. Howe and Koch (1976) presented research on sleepers manufactured by joining two pieces of wood. In the 1970's, sleepers were made by the pressing process of thin sheets, in which red oak logs were folded, dried, and glued into bars in a continuous process (Howe and Koch 1976). Icimoto (2013) manufactured glued laminated wood sleepers using *Pinus oocarpa* and polyurethane adhesive.

The use of glulam techniques has increased in recent decades due to the advancement of adhesive technology and reforestation management. The term glulam refers to the act of gluing material that includes thin pieces of wood to form straight or curved shapes, with all of the sheets fibers parallel to the piece length (Carrasco 1989; Passos 2006; Icimoto 2013). For a better arrangement of the sheets in relation to the wood properties, the sheets must be selected and positioned considering their elastic modulus and the appearance of the parts, and the external tensioned sheets must be classified according to AITC (1992) (Carrasco 1989). This type of structure in most cases requires joints to bond the parts. One of the first studies on finger joints began around 1957 by Rico Laminated Products with a project whose aim was that the joints should reach 80% to 90% of the strength of the corresponding solid wood (Carrasco 1989).

The aim of the present work was to evaluate the manufacturing of new sleepers from the recycling of discharged ones by Brazilian railway companies. The work involved developing manufacturing procedures using the glulam technique and ultrasonic tests, and verifying the reuse rate capacity, all of which may contribute to reducing the environmental impact in the railway operation. So, an environmentally preferable product which minimizes the losses of wood waste and has a low manufacturing cost will be manufactured in this study.

The preservation of the environment has demanded a progressive increase in waste valorization in diverse areas. Ratajczak *et al.* (2015), in work related to resources of post-consumer wood waste, affirmed that the characteristic feature of wood as a raw material is the fact that it is the only major raw material fully reproduced by nature. Also, at the end of their life cycle, products made of wood may be reused or used for energy generation. In addition, such products biodegrade relatively quickly. Laleicke (2018) said that there is momentum towards increasing wood waste utilization, which will enable a truly sustainable resource management; all the benefits along the chain of production, such as the economic ones, to businesses, and to environment should be highlighted.

The present work, aiming to reuse discharged wood and minimize their losses, could be regarded as an example of ecological engineering. Odum (1963) and Bergen *et al.* (2001) defined ecological engineering as "environmental manipulation by man using small amounts of supplementary energy to control systems in which the main energy drives are still coming from natural sources." Environmental manipulation means acting and controlling the environment. To Mitsh and Jorgensen (2003), ecological engineering is the design of sustainable systems, consistent with ecological principals, which integrate human society with its natural environment for the benefit of both." Bergen *et al.* (2001) describe the applications of ecological engineering, which can include the management, use, and conservation of natural resources. The wood sleepers recycling project optimizes the use of this natural resource, contributing to forest conservation and the reduction of deforestation.

Bergen *et al.* (2001) identified five design principles for the ecological engineering project methodology. The present work would fit in the first of them "Designing consistent with ecological principles". "When natural processes are included or reproduced, nature is treated as part of the design and not as an obstacle to be overcome and overwhelmed". One important feature of nature ecosystems is that one process output subsequently become the inputs of other processes, so that there is a self-organization of the ecosystem. Thus, no waste is generated and the nutrients are used again from one level to another. The sleepers recycling project can be considered a facilitator in the self-organization of the ecosystem to which it is related. Wood waste generated by the maintenance of the railways would be processed to serve as raw material for the manufacture of new sleepers.

## EXPERIMENTAL

Procedures were developed for manufacturing glulam wood sleepers of metric gauge, an alternative sleeper type, which was called glulam recycled wood sleeper (GlulamRS).

### Materials and Equipment

For manufacturing of GlulamRS, 46 discharged sleepers were donated by Vale Company (Belo Horizonte, Brasil). The discharged sleepers, according to the Brazilian standard NBR 7511 (2013) "are those which don’t perform well in the railway". Taking into account their service life status, they are commonly classified as half-way (with standard dimensions and some flaws), scrap (with standard dimensions, but with lots of damage), or firewood (broken or badly damaged), as shown in Fig. 1.

(a) (b) (c)

**Fig. 1.** Discharged sleepers classification. (a) half-way; (b) Scrap; (c) Firewood

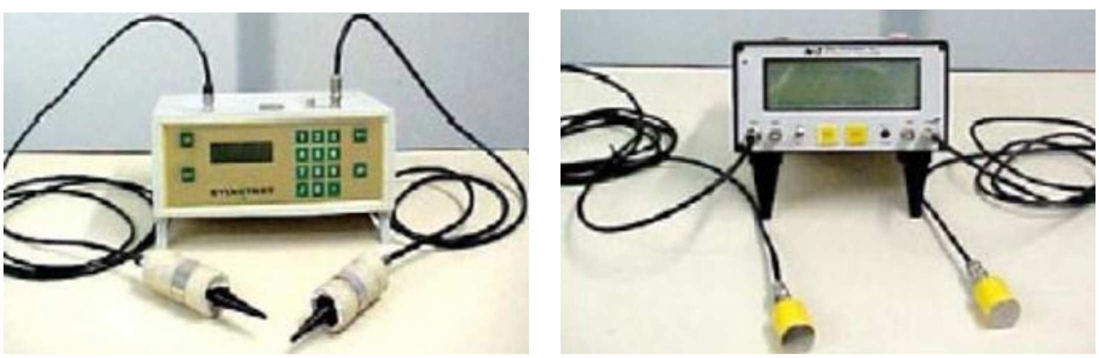
The railway metric gauge and 115-RE rail type (AREMA standard steel rails) were considered, and the minimum and maximum dimensions of the discharged sleepers are shown in Table 1, according to Brazilian standard NBR (Norma Brasileira) 7511 (2013).

**Table 1.** Sleeper Dimensions

| Width (cm) | | Height (cm) | | Length (cm) | |
|---|---|---|---|---|---|
| Minimum | Maximum | Minimum | Maximum | Minimum | Maximum |
| 22.0 ± 2 | 22.0 ± 2 | 16.0 ± 2 | 16.0 ± 2 | 190.0 ± 5 | 200.0 ± 5 |
| 22.0 ± 2 | 22.0 ± 2 | 16.0 ± 2 | 17.0 ± 2 | 200.0 ± 5 | 230.0 ± 5 |

To glue the timber sheets, emulsion polymer isocyarate (EPI) 1974 adhesive was used with the Hardener 1993 catalyst, both from Akzo Nobel-Casco Adhesives (Stockholm, Sweden). The adhesive was chosen due to its relatively low cost, low curing time, and resistance to bad weather. The 1974 EPI adhesive is water-based, with white color, a density of approximately 120 kg/m$^3$, and pH 7. The Hardener 1993 catalyst is isocyanate-based, has a light brown color, and has the same density and pH of 1974 EPI. Instructions from the adhesive manufacturer were followed to determine the proportion and mixing time, adhesive application time, pressure and pressing time, and rest time of the workpiece.

To determine the dynamic elastic modulus ($E_d$) with non-destructive ultrasonic tests, two types of equipment were used. The first one from Sylvatest (Lausanne, Switzerland), uses the exponential transducers of 39 kHz, and the second one, James K Metter II (James Instruments Inc., Chicago, IL, USA), uses transducers of 150 kHz.



(a) (b)

**Fig. 2.** Ultrasonic equipment. (a) Sylvatest with 30 kHz transducer, (b) James MK II transducers of 150 kHz. From Carrasco *et.al.* (2004)

The discharged sleepers were numbered in sequence from 1 to 46, and each of them were marked with three dividing lines along their lengths, dividing them into four equal and numbered parts from Q1 to Q4 (Quadrant 1 to 4) from left to right and each quadrant has 50 cm. The sleepers were weighed, and the height, width, and length of all quadrants was measured. The density of the sleepers was obtained using this information. Any imperfections, cracks, fractures, and flaws caused by insects or fungi were measured and cataloged, as the flaws influence the ultrasonic readings.

The ultrasonic tests were performed on the discharged sleepers to determine $E_d$. The propagation time of the ultrasonic pulse along the sleeper length was measured using the Sylvatest equipment with the 30 kHz transducers positioned directly in four points of each sleeper, with a minimum distance of 30 cm between the transducers based on the recommendation of Duarte *et al.* (2004), as shown in Fig. 3.

(a) (b) (c)

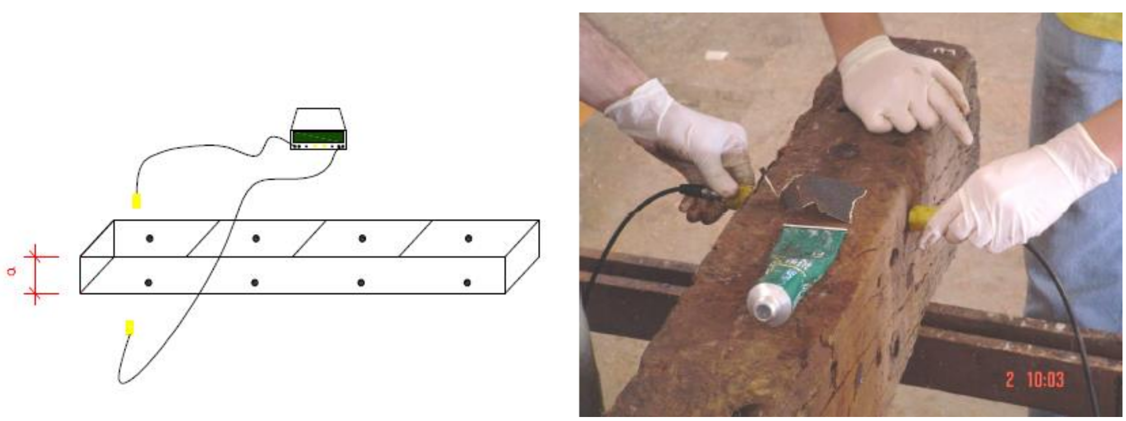
**Fig. 3.** Positioning of the transducers directly along the length of the sleeper. (a) The proposed scheme, (b) sleepers tests, and (c) sheets tests

Considering the length of each piece and the time of the ultrasonic wave course, the speed of propagation of the longitudinal ultrasonic wave and $E_d$ was determined by Eq. 1,

$$E_d = \rho . \frac{v^2}{g} \tag{1}$$

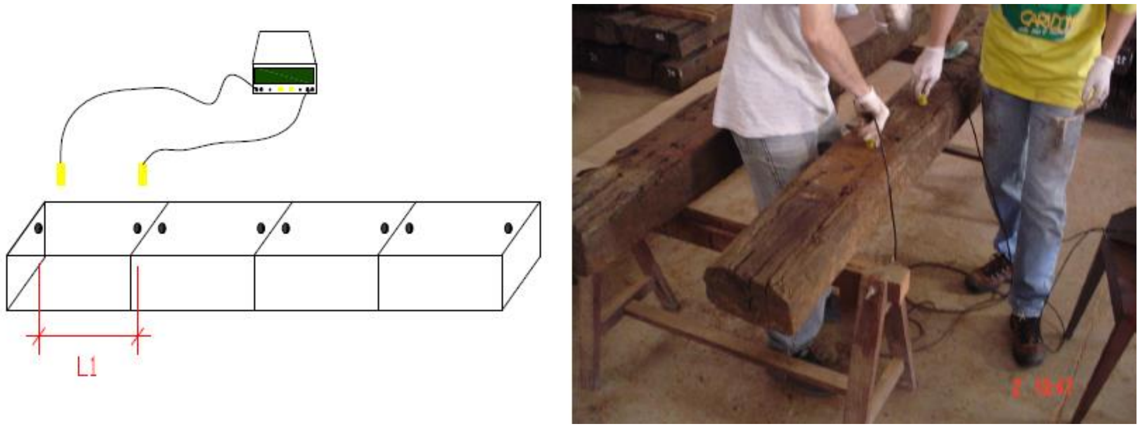
where $v$ is the wave propagation speed (m/s), $\rho$ the wood density (kg/m$^3$), and $g$ is gravity. Wood density values were calculated for each wood sleeper, considering their weight divided per volume.

To determine the propagation time of the pulses in height, width, and length (L1) of each quadrant, James MK II equipment was used, with the 150 kHz transducer positioned directly in height and in width (Fig. 4) and indirect length (Fig. 5).



(a) (b)

**Fig. 4.** Positioning of transducers directly with the transducers MK II over the height and width of each sleeper quadrant. (a) The proposed scheme, and (b) positioning of transducers and test




(a) (b)

**Fig. 5.** Positioning of the transducers in an indirect way along the length of each sleeper quadrant. (a) The proposed scheme, and (b) positioning of transducers and test

## GlulamRS Manufacturing

After the discharged sleepers were tested, they were cut and unfolded into smaller pieces. This procedure was performed in the carpentry shop of the Structural Department of Engineering School of the Federal University of Minas Gerais.

To cut the sheets, the discharged sleepers were first brought to the planer, to the left or right surface, and subsequently the upper or lower surface, where it was flattened, thereby obtaining the square between the two faces. Next, cuts of 36 mm thickness were made with a circular saw. Flaws and defects were removed from the sheet side and mainly from the sheet top, as the top bonds would be made by finger-joint and in this type of bond there cannot be any flaws in the wood.

The ultrasonic tests were performed again with Sylvatest equipment with the transducers positioned directly over the length of at least two parts of each sleeper. The dimensions and weight of the pieces were measured in order to obtain $E_d$. They were trimmed to obtain a standard thickness of 34 mm with a circular saw. For a better use of the sheets, the existing holes were filled with a compound obtained from the EPI-1974 (2003) adhesive mixed with sawdust from the sleepers.

Mapping was carried out for the newly manufactured sleepers using the $E_d$ values of the wood sheets. Sheets with higher $E_d$'s were disposed on upper and lower surfaces of the GlulamRS. The sheets with intermediate values of $E_d$ were positioned so as to achieve better utilization, as they had different values of width and length. To obtain a better utilization of the timber and make the process more productive, 4 m long pieces were manufactured using finger-joints, which enabled two GlulamRS to be produced. During the process, some sheets were either replaced, their positions were exchanged, or their dimensions were altered, as some of them would fit better elsewhere. Other sheets which still had flaws at this stage were recovered or replaced.

Figure 6 shows the joining of the top sheets with a 25 mm length finger joint. These joints were made with cutters in a modified router using three cutting mills and a finish mill. The cuts of the sheets were made gradually to avoid damaging the cutters because the wood had great hardness and some of them were too oily from the chemical preservative treatment.

This led to the formation of a film, which along with the rotation of the router caused the cutting blade loss, requiring the blade to be sharpened. For bonding each finger-joint, the EPI adhesive 1974 and the Hardener 1993 catalyst were used. The sheets were joined together, lined up, and pressed using a hand press and with a 1 MPa pressure. The entire process, except for the pressing, lasted about 6 min. After 24 h of pressing, the width of the pieces bonded with finger-joint was standardized in using a circular saw.

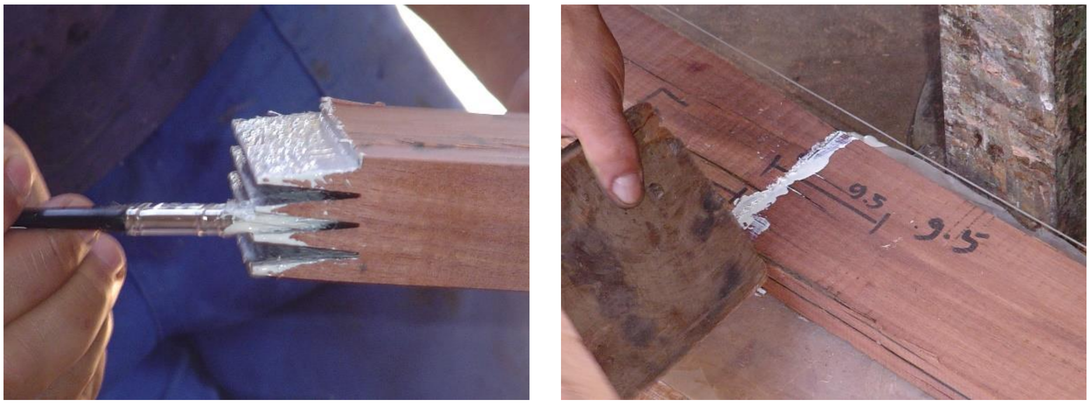



**Fig. 6.** Adhesive application in the manufacture of finger-joint

For the lateral union of the pieces, male and female bond types were used, as shown in Fig. 7. The pieces were cleaned and placed in a hydraulic press with a pressure of 1 MPa for about 24 h. The minimum pressing time, in accordance with the manufacturer, is 30 min. However, this time was overestimated, as the effects on the glued surface by the presence of chemical preservatives in wood were unknown. After pressing, the sheets were joined by male and female joint, according to Fig. 7 to have a standard width of 22.5 cm.

(a) (b) (c)

**Fig. 7.** Gluing stages of male and female joint, (a) Applying glue in the pieces; (b) pieces being arranged in the hydraulic press, (c) Pieces joined by male and female joint

After 24 h, the recommended time to start working on the pieces, the extra glue was removed from male and female joint types of the glued pieces. After the adhesive cure, sheets were trimmed until they reached the standard thickness of 32.5 mm. The thickening process and the sheets pressing were performed the same day. The surfaces of all sheets were cleaned with manual brushes before being joined together. Then one adhesive was prepared to a consumption of 360 g/m$^2$ before being applied on both sides of the sheets for manufacturing GlulamRS.

The sheets were placed in the hydraulic press to begin the process of bonding, which lasted approximately 12 min at an average temperature of 31 °C (over the recommended value). The bonded sheets were pressed for a period of 24 h at a pressure of 1 MPa and at room temperature (25 °C and relative humidity of 68%). After this stage the finishing process began. Each piece of GlulamRS was approximately 4.20 m in length using 2 to 4 finger joints, depending on the flaws. These were taken to the circular saw and divided into two GlulamRS, 2 m long each. To obtain sleepers with a good square and dimensions shown in Table 1, the upper face and the side faces were brought to the planer and then the other two sides were referred to thickness planing machine.

Finally, all the GlulamRS surfaces were sanded with 36 weight and 60 weight sandpaper and then weighed to obtain density. The values for the GlulamRS density were between 915 kg/m$^3$ to 1000 kg/m$^3$, over the minimum values required by NBR 7511 (2013) for a sleeper class I (750 kg/m$^3$).

Mass losses were analyzed for the sleepers to verify the amount of natural raw material to be recycled. The volumes of each discharged sleeper were compared to the standard volume of a new sleeper metric gauge with dimensions of 16 cm x 22 cm x 200 cm, and a loss of 14% was found.

## RESULTS AND DISCUSSION

The sleepers discarded on the railroad that were used in the process had 14% less wood available for recycling.

After making the sleepers cuts, all the unfolded pieces were measured and weighed to determine the density and the rate of recycling material. The reuse rate of each sleeper ranged from 7.29% to 59.60%. However, the average reuse rate was 24%, which indicated that one GlulamRS can be obtained using about four or five discharged sleepers.

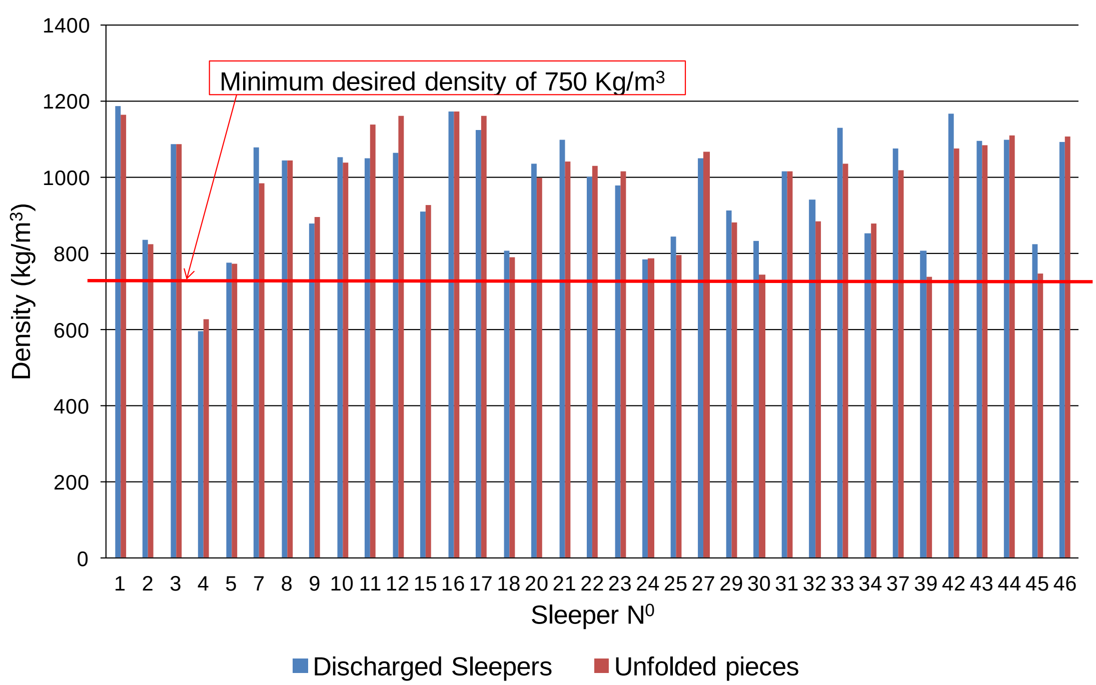



**Fig. 8.** Density of the discharged sleepers and the unfolded pieces

The density of the discharged sleepers was compared with the average density of the unfolded pieces of these sleepers, and results are shown in Fig. 8. Only four sleepers had densities lower than 750 kg/m$^3$, and among them the only one had a density of less than 700 kg/m$^3$. This showed that, regarding density, the discharged sleepers achieved the minimum value required by the NBR 7511 (2013) for Class 1. Thus, wood waste generated in maintenance of railways may have a potential to be processed and used as raw material for new sleepers.

To determine whether the density and $E_d$ of the discharged sleepers and the unfolded pieces can be considered equal, a statistical analysis of the null difference hypothesis was made with a 95% degree of uncertainty. For the density, the confidence interval (CI) was (-14.37; 18.68) kg/m$^3$, and for $E_d$ (-1401; 74.10) MPa, which indicated that the values obtained in the discharged sleepers before and after they were unfolded could be considered statistically equal with level of 95% reliability. This indicated that the measurement of two properties could be performed in only one of the unfolded parts, from the selected ones in the batch that were proper for reusing, thus simplifying the process of the $E_d$ determination. Sleepers 16 and 42 showed inconsistent and widely dispersed values, and for this reason they were not taken into account in the analysis.

The $E_d$ values indicated that the ultrasonic test in the discharged sleepers was not advisable due to the large number of flaws that interfere in the propagation of waves, as shown in Fig. 9. Taking as an example the sleeper 42, the $E_d$ value found in the ultrasonic test sleeper was equal to 2,713 MPa, and the value of $E_d$ in the ultrasonic test for the unfolded pieces increased to 21,493 MPa, which indicated that the first measurement was impaired by internal existing flaws in the sleeper.

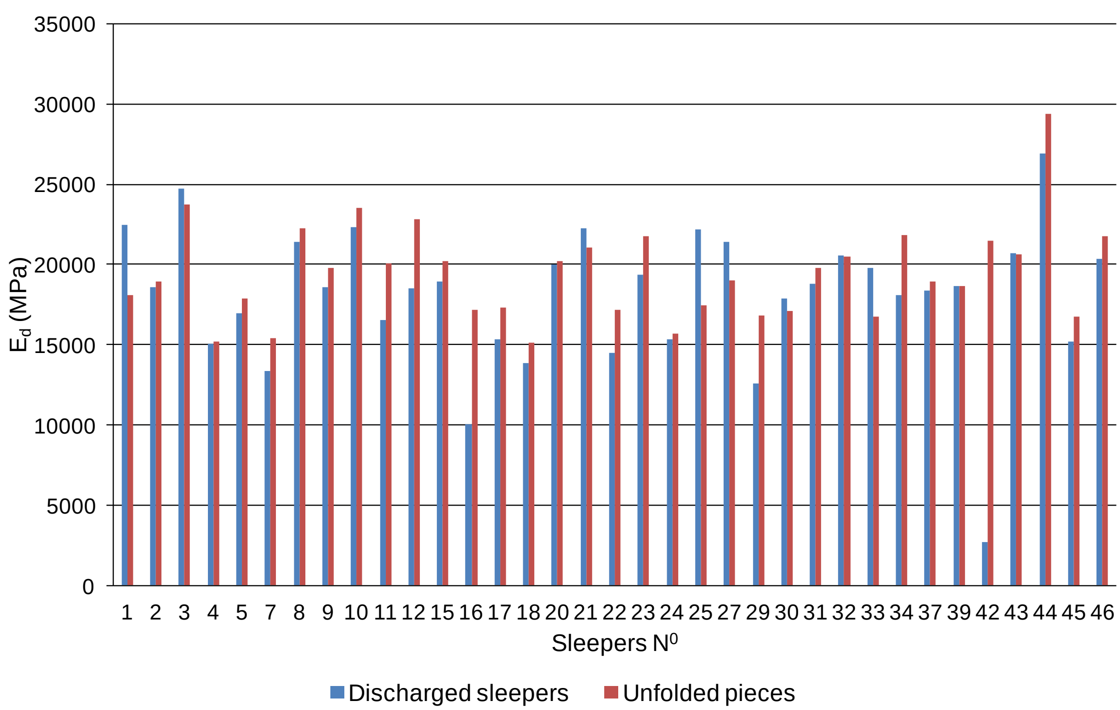



**Fig. 9.** $E_d$ form discharged sleeper and unfolded pieces

## CONCLUSIONS

1. It is not advisable to determine the discharged sleepers' dynamic elastic modulus ($E_d$) by using ultrasonic testing because of the probability of internal flaws masking results. $E_d$ should be determined on an unfolded sleeper.
2. In the GlulamRS manufacturing process, the sheets mapping may be carried out by determining the density or $E_d$, using ultrasonic techniques. These characteristics may be determined in just one unfolded sleeper sheet, and the values obtained can be used for the other sleeper sheets with the same characteristics, which can simplify the process.
3. The time readings of the ultrasonic wave courses along the length of the sleepers was satisfactory, but in many occasions, readings were not obtained along the width. The outer edge was exactly where the sleepers had many defects, so it is recommended that, to obtain greater use of recycled material, it should be cut along the width.
4. It was possible to obtain a wood sleeper from recycling four to five discharged sleepers. Although the reuse rate was not high because of the flaws and the unfolding process, a methodology of manufacturing GlulamRS was developed. It was demonstrated that it may be possible to reuse the discarded sleeper to contribute either for the railway operation process or to the conservation of the natural resource and ecosystem balance. So, making it possible to reusing discharge materials, this work contribute to reducing environmental impacts in railway operation.
5. As a future study, bending, shear and fatigue tests should be done in the GlulamRS to assure that an industrial production can be possible. In the case of industrial production, the techniques should be adapted for large-scale operations, as the present work was carried out in the laboratory.

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