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From Plastic Waste to Building Material: Mechanical Properties of Recycled Thermoplastic Timber

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Abstract: The present paper illustrates the mechanical properties of a new structural product called Recycled Thermoplastic Timber (RTT), manufactured in Sardinia (Italy) and made of recycled plastics. The preliminary results of an experimental campaign aimed at assessing the main mechanical and physical properties of RTT are presented and discussed. Unreinforced and steel-reinforced thermoplastic timber profiles have been tested in laboratory and some mechanical and physical properties have been evaluated also varying the climatic conditions. Furthermore, weathering properties have been checked by testing the resistance to freezing and thawing. In light of the results since now achieved the prospect of using RTT as an eco-friendly alternative to wood and other building materials is discussed.

Keywords: Waste Treatment, Innovative Building Materials, Sustainable Composites, Recycled Plastics, Thermoplastic Timber

Introduction

In the last thirty years a considerable increase of plastic consumer goods has determined an augmentation in polymer manufacturing and, thus, in waste generation (Lupo *et al*., 2016).

Plastic materials are extremely resource efficient not only in their production phase but also during their use phase.

In some applications like insulation, during service life plastic materials save more than 140 times the energy needed for their production. They have outstanding performance when it is necessary to protect goods and food (PlasticsEurope, 2016).

World and European production of plastic materials in 2016 was 335 and 60 million tons respectively. That includes plastic materials (thermoplastics and polyurethanes) and other plastics (thermosets, adhesives, coatings and sealants), but does not include Polyethylene Terephthalate (PET), Polyamide (PA), PolyPropylene (PP) and polyacryl-fibers. China is the largest producer of thermoplastics and polyurethanes plastic materials with 29%, followed by Europe (19%) and North American Free Trade Agreement (NAFTA) which production represents the 18% of the world's total production (PlasticsEurope, 2017).

Packaging represents the largest application sector for the plastic industry with 39.9% of the total European plastic demand. Building and construction is the second sector (19.7%), followed by automotive (10%), electrical and electronic (6.2%) and household, leisure and sports applications (4.2%) (Lupo *et al*., 2016; PlasticsEurope, 2017).

In 2016, the European plastic demand by type was: 19.3% of PP, 17.5% of low-density and linear low-density PolyEthylene (PE-LD, PE-LLD), 12.3% of High Density and Medium Density PolyEthylene (PE-HD, PE-MD), 10% of PolyVinyl Chloride (PVC), 7.5% of PolyURethane (PUR), 7.4% of PET, 6.7% of PolyStyrene and PolyStyrene Expandable (PS, PS-E) and 19.3% of other plastics (PlasticsEurope, 2017). The low cost of manufacturing, light weight and durability have increased the applications of plastic materials so that some traditional materials, such as wood, metals and ceramics, have been replaced in production of consumer goods (Lopez *et al*., 2017; Wong *et al*., 2015). Moreover, the development of new plastics together with composite materials have extended even more their applications (Lopez *et al*., 2017).

Consequently, plastic waste management is becoming a main focus, because many applications are characterized by a short life and recycling alternatives for plastic waste are currently costlier than landfilling and incineration, excluding energy recovery (Lupo *et al*., 2016; Lopez *et al*., 2017; Wong *et al*., 2015). Recycling is the preferred option for plastics waste. However, when recycling is not the most sustainable option, energy recovery is the alternative. In 2016, 27.1 million tons of post-consumer plastics waste ended up in the official waste streams and for the first time more plastic waste was recycled than landfilled: 31.1% was recovered through recycling (more than 8.4 million tons of plastics waste were collected for recycling), 41.6% went to energy recovery processes, while 27.3% still went to landfill (PlasticsEurope, 2017).

Several techniques have been developed in order to separate and sort plastic waste and to minimize landfill. Three great families can be defined (Panda *et al*., 2010):

(i) *Mechanical recycling*: It is divided into *primary recycling* when plastic waste is sorted into homogeneous groups and converted into products with nearly same or less performance level than the original product and *secondary recycling* when plastic waste is sorted-mixed and the derived products have lower performances than the original one
(ii) *Chemical recycling:* Also known as *tertiary recycling*, aims to convert polymer waste into original monomers or other valuable chemicals by means of pyrolytic, chemolytic or hydrocracking processes (Panda *et al*., 2010; Lopez *et al*., 2010; Al-Salem *et al*., 2010; Wong *et al*., 2015) and involves the use of polymer waste arisings as a feedstock for those used to break down polymeric waste into simpler substances subsequently re-polymerized in order to produce virgin materials
(iii) *Thermal recovery* or *quaternary recycling* exploits the calorific content. All polymers have a high heat content so that incineration with energy reclamation offers a way of winning back some value from polymer waste where the level of contamination or the degree of mixing makes any other process economically unattractive (Panda *et al*, 2010; Lopez *et al*., 2010; Al-Salem *et al*., 2010; Wong *et al*., 2015)

Since recycled plastics may be obtained from various sources, having been exposed to different storage and reprocessing conditions, they may therefore exhibit different performance depending on their degradation level (Kazemi Najafi, 2013).

A new structural thermoplastic composite, made of 100% recycled post-consumer plastics that would otherwise be discarded into landfills, is commonly called Recycled Thermoplastic Timber (RTT).

This kind of material was originally developed in conjunction with scientists at Rutgers University by an American manufacturing company, the Axion International Inc., at the end of the XX century. This environmentally friendly thermoplastic material was first used in railroad crossties and its application has recently been extended to bridge and structural members (Chandra *et al*., 2012). For example, recycled plastic lumber has been used to replace wood in some construction applications, especially outdoors, but the structural properties of these materials have not been well-studied yet (Krishnaswamy and Lampo, 2001; Carroll *et al*., 2001).

The primary disadvantage of RTT is the lack of 'performance-based standards' that ensure the success of the material in structural applications. Moreover, most of the companies do not have adequate quality control programs in order to certify that their products meet the minimum requirements for structural uses (Lampo, 1995; Krishnaswamy and Lampo, 2001). Several producers studied mixtures of two or more polymer types added with different materials (i.e., sawdust, glass fibers, resins) in order to improve some physical or mechanical properties (Carroll *et al*., 2001; Bajracharya *et al*., 2014). The challenge for the XXI century is to develop a sustainable and easy technology to improve the production of a structural RTT made of 100% of plastics.

In this study the preliminary results of an experimental campaign aimed at assessing the main physical and mechanical properties of a 100% RTT, manufactured in Sardinia (Italy), are analyzed and discussed.

Materials

The base material of the RTT is derived entirely from the separate waste collection carried out in Sardinia. It is obtained from the recycling of plastic waste such as bottles, bags, films, packaging, food containers and other recyclable products like PET, PE-HD, PE-LD, PP and PS.

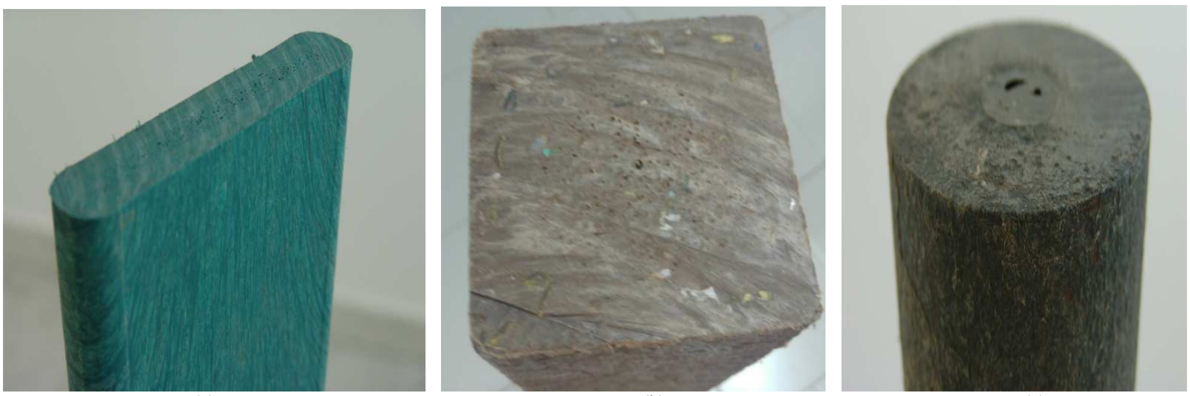
The recycling process for producing RTT is a mechanical process that, differently from the chemical recycling, does not produce emissions in the atmosphere and leads to a good quality of the material. On the other hand, it is a complex manufacturing process that results in a more expensive product.

The first steps of the production process are the sorting and the washing: Every plastic item is separated into two production lines according to type and texture (Fig. 1) and then it is properly washed for removing all the impurities such as labels and adhesives.

The second step is the shredding: Waste is reduced into small flakes and granules by means of two shredding machines, one for each production line. Films and bags are compressed into a densifier, where the material is heated to a temperature of 100/105°C and then cooled with water. Then the material is stored in separate silos (Fig. 2): One for PE-LD, one for PE-HD and one containing PET, PP and PS. This distinction is necessary because each material guarantees certain qualities to the final product: As an example, PE-LD has a good ease of processing and provides high flexibility and a moisture barrier, PE-HD guarantees stiffness and mechanical strength, while PET supplies an aptitude to be easily colored.

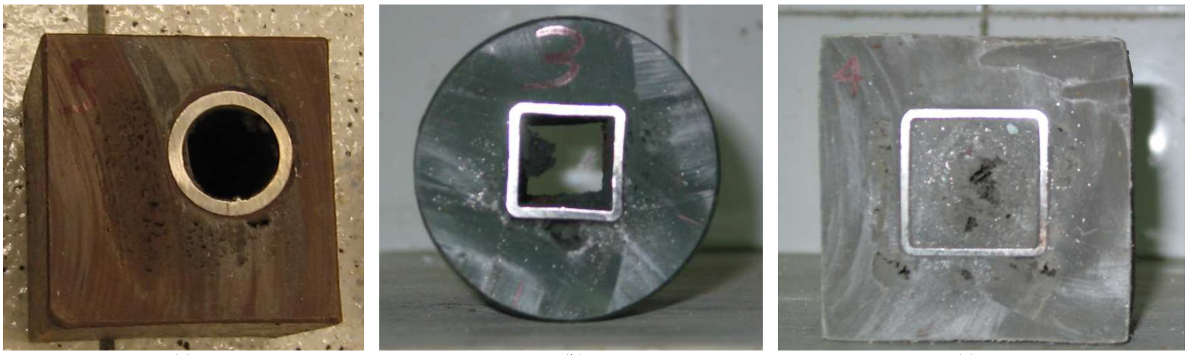
Fig. 1: Sorting of plastic waste

Fig. 2: Storing silos



(a) (b) (c)

Fig. 3: Type of profiles: (a) lumber (b) square (c) cylinder



(a) (b) (c)

Fig. 4: Steel-strengthened profiles

A proper mix is studied in order to obtain an optimum final product: The mixture consists approximately of 45-50% PE-LD, 45% PE-HD, 5% PET and the remaining includes PP, PS and pigments which slightly vary in percentages depending on the type of element to be produced and the demands of customers.

The final step of production is the extrusion: The mixture is led to 200°C and moldered into different shapes and profiles (Fig. 3) that are cooled for 2-3 min in water. Profiles are naturally dried on racks and finally they are ready for storage and for sale. If required, some section can be reinforced by including a tubular (round or square) steel element in the core (Fig. 4).

Experimental Program

This research aims for better understanding the structural properties of the RTT made of 100% recycled plastics. In the following the preliminary results concerning some physical (density and water absorption) and mechanical (compressive, tensile and flexural strength) properties are presented.

Due to the lack of technical rules governing the production and the standard requirements for RTT, tests have been carried out either according to European Standards for plastics in general, or according to procedures specifically studied in order to check a particular property.

The experimental program has been carried out on both steel-strengthened and un-strengthened profiles: Cubic specimens having a side section of 80 mm and 108 mm respectively and cylindrical specimens having diameter of 80 mm and height of 160 mm have been derived from commercial profiles. Moreover, specimens with parallel sided central section have been derived from un-strengthened profiles in order to check the tensile properties.

Tests have been performed (1) at room temperature, on specimens as they were; (2) after freezing and thawing cycles for simulating a weathering action and (3) at a temperature of 60°C for reproducing summer conditions.

A total of 50 freezing-thawing cycles have been applied, each one according to the following program:

1. T = 20°C
2. T = 20°C for 30 min
3. from T = 20°C to T= 0°C in 180 min
4. T = 0°C for 250 min
5. from T = 0°C to T= -17°C in 180 min
6. T = -17°C for 240 minutes
7. from T = -17°C to T = 20°C in 60 min
8. T = 20°C for 420 min in water
9. T = 20°C for 30 min without water

Density and Water Absorption

Tests have been carried out only on un-strengthened specimens according to UNI EN ISO 1183-1 *Plastics - Methods for determining the density of non-cellular plastics - Part 1: Immersion method, liquid pyknometer method and titration method.*

Density has been evaluated by the immersion method and calculated by means of the application of the Archimedes principle.

The RTT specimens have been weighted and then immersed in deionized water at 23±2°C suspended by a sinker of lead attached to a corrosion-resistant wire. All adhering bubbles have been removed and the weight of immersed specimens have been recorded.

The density ρ_s (g/cm^3) has been calculated according to the following equation:

$$\rho_s = \frac{m_{sa} \cdot \rho_{IL}}{m_{sa} + m_{k,IL} - m_{s+k,IL}} \tag{1}$$

Where:

m_{sa} (g) = The apparent mass of the specimen in air
ρ_{IL} (g/cm^3) = The density of the immersion liquid at 23°C
$m_{k,IL}$ (g) = The apparent mass of the sinker in the immersion liquid
$m_{s+k,IL}$ (g) = The total apparent mass of the specimen and the sinker in the immersion liquid

A total of 45 un-strengthened specimens (cubes sized respectively 80 mm and 108 mm and cylinders) have been tested for measuring density, 15 for each section type. Results, sorted for each type of section, are summarized in Table 1.

Then, three samples for each section type have been tested for measuring water absorption. The specimens have been placed in an oven, dried until constant mass and then weighted. Afterwards, they have been submerged in water and weighed at different times until a constant mass was reached: The first weigh has been registered after one hour, the last after 45 h. The results are shown in Table 2.

The RTT specimens showed lower density values than water. As shown in Table 1, the highest measured density pertains to cylindrical specimens (0.913 g/cm^3), while the lowest, 0.703 g/cm^3, pertains to cubic specimens sized 108 mm. Scattering of density is due to differences in porosity, probably caused to the variable quantity of polystyrene used in the mixture.

Fig. 5: Voids and air bubbles entrapped in the core of the specimen

Table 1: Density

Value	Cubes 80 mm	Cubes 108 mm	Cylinders
Max (g/cm^3)	0.869	0.776	0.913
Min (g/cm^3)	0.838	0.703	0.703
Mean (g/cm^3)	0.853	0.740	0.776
St. Dev. (g/cm^3)	0.012	0.024	0.071
C.o.V. (%)	1.41	3.24	9.15

St.Dev. = Standard Deviation; C.o.V. = Coefficient of Variation

Table 2: Water absorption test

Specimen	Abs_{1h} [%]	Abs_{45h} [%]
Cube 80 mm	0.09	0.14
Cube 108 mm	1.10	1.43
Cylinder	0.81	1.25

Abs_{1h} = water absorption after one hour
Abs_{45h} = water absorption after 45 h

Air generated during the extrusion process remains entrapped within the section and generates voids and air bubbles (Fig. 5). Nevertheless, this porosity does not affect significantly the density: The maximum variation of density due to the porosity of the material has been recorded for cubes having 108 mm of side section, which showed the lowest density and the highest values of water absorption due to the voids generated by the air entrapped in the section. Anyway, the weight increment due to the porosity is very poor: Maximum value recorded is 1.43% (Table 2).

Compression Tests

Compression tests have been carried out according to UNI EN ISO 844 (2014) - *Rigid cellular plastics - Determination of compression properties*.

The Standard specifies a method for measuring: (i) The compressive strength and the corresponding relative deformation or the compressive stress at 10% of deformation (σ_{10}) evaluated in function of the force F_{10}, corresponding to 10% of deformation; (ii) the compressive modulus of elasticity (E).

Tests have been carried on both parallel and orthogonal directions to the extrusion axis of 11 un-strengthened and 10 steel-strengthened cubic specimens 80 mm sized.

Strengthening was realized by means of a steel-tube having diameter of 33.4 mm and thickness of 2.5 mm embedded in the section.

Compression tests have been performed: (1) at room temperature, (2) after weathering treatment (freezing and thawing cycles) and (3) at high inner temperature (60°C).

The compressive strength at 10% of deformation σ_{10} (N/mm^2) has been calculated as the ratio between the force F_{10} (N), corresponding to 10% of deformation and the geometric cross section A_0 (mm^2) of the specimen. The steel reinforcement has not been considered for calculating A_0. The compressive modulus of elasticity has been calculated as:

$$E = \frac{F_e \cdot h_0}{A_0 \cdot x_e}\left(N / mm^2\right) \tag{2}$$

Where:

F_e (N) = The applied force in the conventional elastic zone (defined by the straight portion of the force-displacement curve)
h_0 (mm) = The initial height of the specimen
x_e (mm) = The displacement at F_e, measured by extensometer

Moreover, the compression stress σ_e (N/mm^2) and the corresponding deformation ε_e evaluated at the conventional proportional limit defined by the straight portion of the force-displacement curve have been evaluated. The stiffness:

$$K = \frac{dF}{dx}\left(N / mm\right) \tag{3}$$

was calculated as a linear regression of the ratio between the applied load F (N) and the corresponding displacement x (mm). Results are summarized in Table 3 and 4 for un-strengthened specimens and in Table 5 and 6 for steel-strengthened specimens.

Discussion of Compression Tests Results

Freezing-thawing cycles seem to not affect the RTT properties significantly: As an example, Fig. 6 shows the load-displacement curves of some tested specimens at different conditions. Cubic specimens subjected to weathering treatment show, on average, a stiffness K slightly higher and a compression strength lower than those tested at room temperature; this behavior is observed when the load is applied in parallel but not orthogonally to the extrusion direction (Table 3 and 4). Anyway, the results are highly scattered, as Table 7 shows with reference to the stiffness of un-strengthened specimens.

An opposite behavior is registered when tests are carried out at high temperature. Mechanical properties of the material decay suddenly for the load applied along the extrusion direction, as shown in Table 3 and Fig. 6. No tests at high temperature have been carried out applying loads orthogonally to the extrusion direction.

Steel-strengthening improves considerably both compressive strength and stiffness (Table 5), but when the load is applied orthogonally to the extrusion axis the effectiveness of the reinforcement is very low and stiffness and strength are quite similar to those measured on the un-strengthened specimens. As an example, Figure 7 shows the load-displacement curve for two strengthened and un-strengthened specimens loaded along the orthogonal direction.

Table 3: Un-strengthened specimens. Parallel compression tests

Condition	σ_{10}	F_{10}	ε_e	σ_e	E	K
R.T.	15.70	96.60	0.075	12.42	199.03	15378.64
W. T.	14.89	92.02	0.062	11.00	205.79	16000.27
H. T.	4.66	28.75	0.082	4.45	45.59	3877.87

R.T. = Room Temperature; W.T. = After Weathering Treatment; H.T. = High Temperature (60°C); $\sigma_{10,}$ σ_e and E in (N/mm^2); F_{10} in (kN); K in (N/mm)

Table 4: Un-strengthened specimens. Orthogonal compression test

Condition	σ_{10}	F_{10}	ε_e	σ_e	E	K
R.T..	12.25	76.65	0.047	7.93	178.02	12988.49
W. T.	9.63	60.39	0.055	7.04	154.30	11564.70

R.T. = Room Temperature; W.T. = After Weathering Treatment; σ_{10}, σ_e and E in (N/mm^2); F_{10} in (kN); K in (N/mm)

Table 5: Steel-strengthened specimens. Parallel compression test

Condition	σ_{10}	F_{10}	ε_e	σ_e	K
R.T.	33.58	220.13	0.069	33.58	45872.82
W. T.	23.38	172.99	0.040	23.38	40132.90

R.T. = Room Temperature; W.T. = After weathering treatment; σ_{10}, σ_e in (N/mm^2); F_{10} in (kN); K in (N/mm)

Table 6: Steel-strengthened specimens. Orthogonal compression tests

Condition	σ_{10}	F_{10}	ε_e	σ_e	K
R.T.	11.67	74.69	0.04	7.29	17024.37
W. T.	9.90	63.73	0.05	7.10	12177.32

R.T. = Room Temperature; W.T. = After weathering treatment; σ_{10}, σ_e in (N/mm^2); F_{10} in (kN); K in (N/mm)

Table 7: Stiffness of un-strengthened specimens

Condition	K (N/mm)	St. Dev.(N/mm)	C.o.V. (%)
R.T.	15378.64	3264.55	21.23
W. T.	16000.27	1449.55	9.06
H.T.	3877.87	948.82	24.47

K = Stiffness; St. Dev. = Standard Deviation; C.o.V. = Coefficient of Variation; R.T. = Room Temperature; W.T. = After weathering treatment; H.T. = High Temperature (60°C)

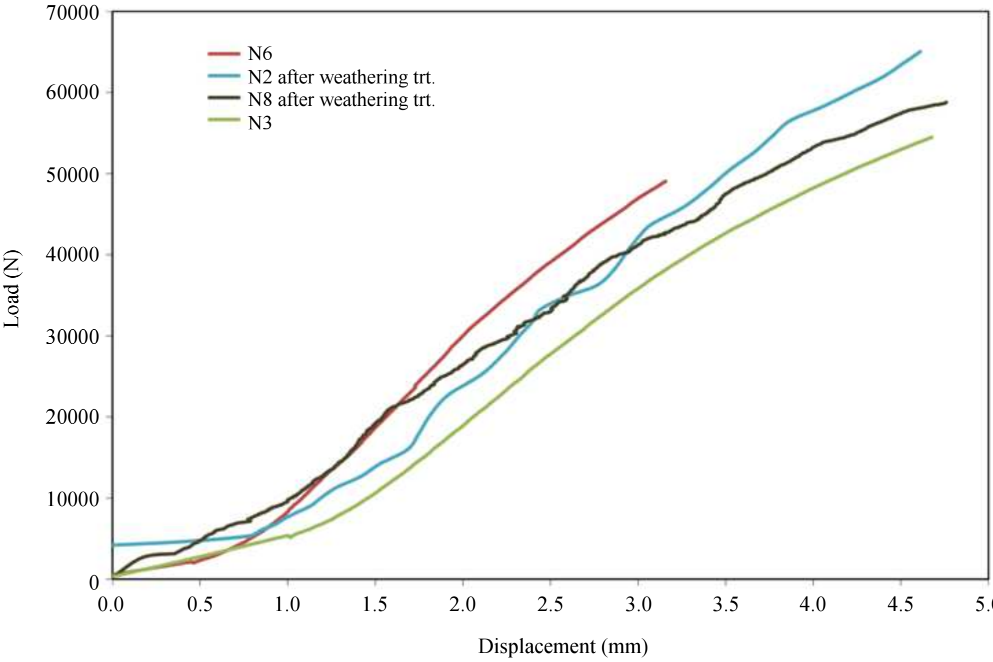


Fig. 6: Load displacement curvesun-strengthened specimens

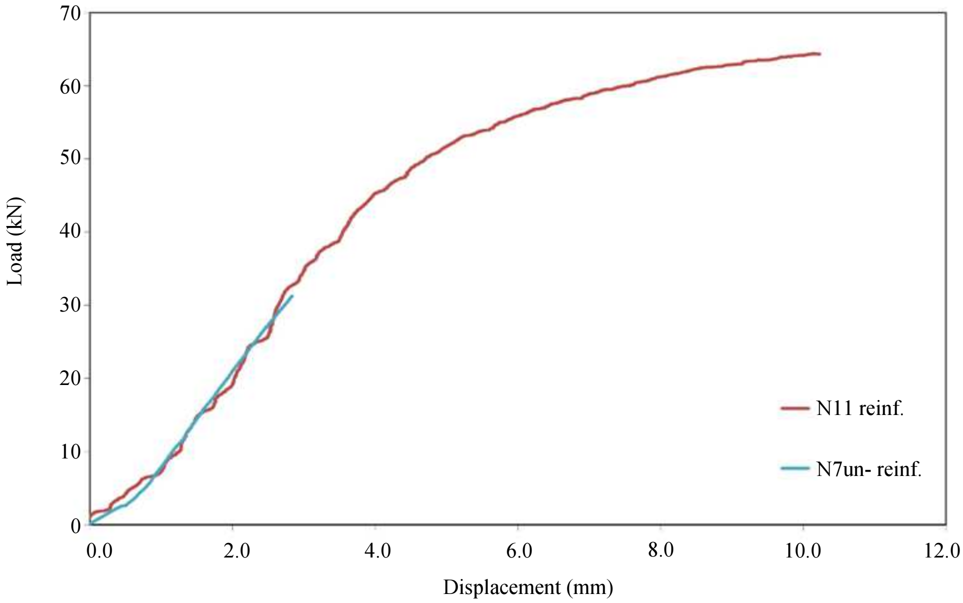


Fig. 7: Load displacement curve-load orthogonal to extrusion direction

Weathering treatments do not affect significantly the mechanical properties of strengthened specimens: Both ultimate compression load and stiffness are quite reduced, but the differences could be typical of a lot-to-lot variation (Table 5 and 6). Anyway, further tests should be carried out in order to prove this behavior. No tests have been carried out on strengthened specimen at high temperature.

Tensile Tests

Tensile tests have been carried out according to UNI EN ISO 527-1 (2012) *Plastics - Determination of tensile properties - General principles.*

Twelve dog-bone shaped specimens (Fig. 8) have been derived from commercial profiles according to UNI EN ISO 527-2 (2012) *Plastics Determination of tensile*

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properties - Test conditions for moulding and extrusion plastics. The tests have been run at room temperature.

Specimens have been shaped mechanically from commercial profiles and they have a mean parallel sided central section of 25×10 mm and a total length of 200 mm.

The tensile strength σ_t (N/mm^2), the yielding stress σ_y (N/mm^2) (the stress measured at the end of the straight portion of the force-displacement curve) and the corresponding tensile deformation ε_t and yielding deformation ε_y have been measured during the tests by means of a load cell and an extensometer on the tensile machine. The tensile modulus of elasticity E_t (N/mm^2) has been calculated from the force-displacement curves.

The results, summarized in Table 8, show a high scattering: It can be observed from Fig. 9 that specimens exhibit both ductile and fragile (shear) rupture types. When the ductile rupture arose, a big reduction of the section occurred and elongations over 10% were measured. On the contrary, when shear rupture occurred, both load bearing and elongations were drastically reduced (Table 8). The great scattering of the results suggests to better check tensile strength and stiffness by means of further tests.

Flexural Tests

Three-point bending tests with a span length of 500 mm have been carried out according to the flexural test set-up showed in Fig. 10.

The specimens have been cut from square RTT profiles (section 80x80 mm) at a length of 600 mm as shown in Fig. 11.

Except for the specimen dimensions, tests have been carried out according to UNI EN-ISO 178 (2013) *Plastics - Determination of flexural properties*.

The bending strength has been calculated according to the following formula:

$$\sigma_f = \frac{3 \cdot F \cdot L}{2 \cdot b \cdot h^2}\left(N / mm^2\right) \quad (4)$$

Where:

F (N) = The maximum flexural load

L (mm) = The span length of the specimen

b (mm) and h (mm) = Respectively the width and the height of the cross section of the specimen

Table 8: Tensile test results

Value	σ_y (N/mm^2)	σ_t (N/mm^2)	E_t (N/mm^2)	ε_y (%)	ε_t(%)
Mean	8.25	12.66	237.06	0.08	3.32
Max	14.34	19.07	431.03	0.14	10.36
Min	2.28	2.45	118.35	0.03	0.23

σ_y = yielding stress; σ_t = tensile stress; E_t = tensile modulus of elasticity; ε_y = yielding deformation; ε_t = tensile deformation

Fig. 8: Specimen for tensile test

Fig. 9: Profiles after tensile rupture

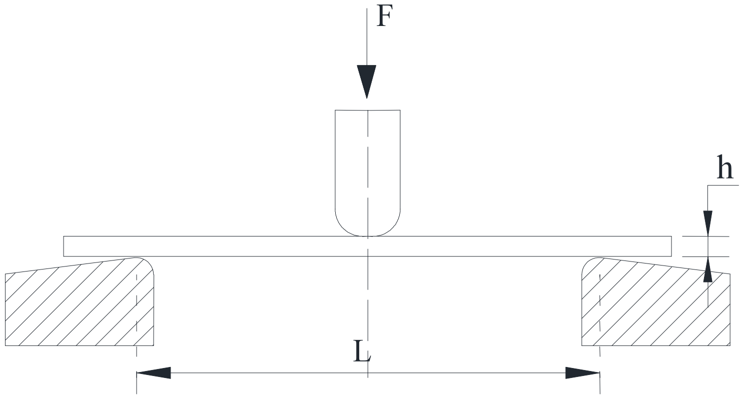

Fig. 10: Flexural test set-up

Fig. 11: Specimen for flexural test

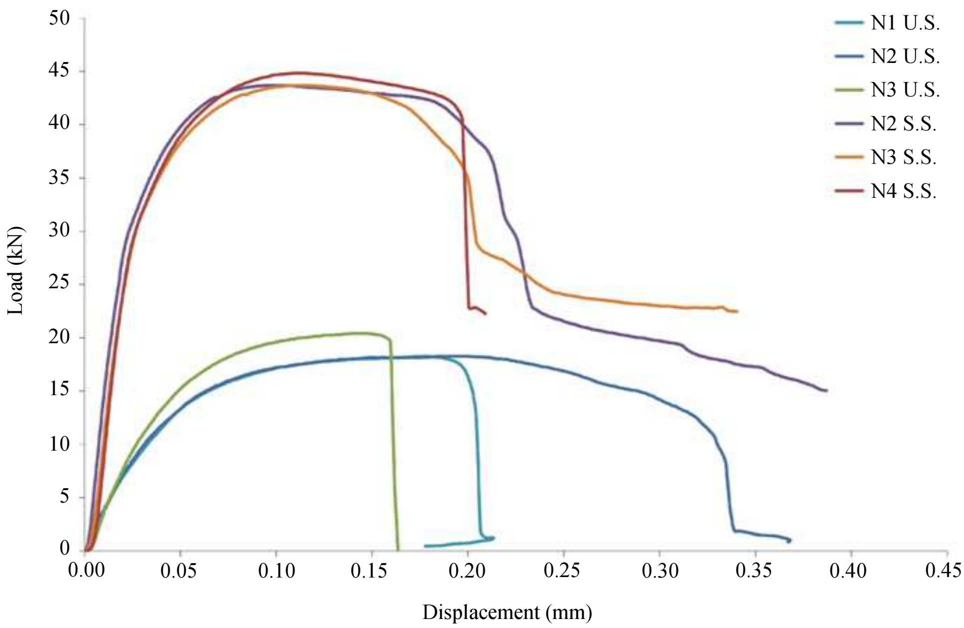

Fig. 12: Flexural tests

Table 9: Flexural test results

Specimens	σ_{fM} (N/mm^2)	σ_{fe} (N/mm^2)	ε_{fe} (%)	ε_{fM} (%)	E_f (N/mm^2)
U.S.	18.80	8.09	2.37	18.23	373.3
S.S.	44.08	24.72	1.96	10.77	1290.2

U.S. = Un-strengthened; S.S. = Steel strengthened; σ_{fM} = maximum flexural test; σ_{fe} = elastic flexural test; ε_{fe} = elastic flexural strain; ε_{fM} = maximum flexural strain; E_f = modulus of elasticity in bending

The strain in bending ε_f has been calculated as:

$$\varepsilon_f = \frac{6 \cdot s \cdot h}{L^2} \tag{5}$$

Where:
s (mm) = The deflection measured over the entire span
h (mm) = The thickness of the specimen

A wire extensometer has been used to measure the deflection of the mid span of the beam. The maximum flexural stress σ_{fM} (N/mm^2) sustained by the specimen during the tests, the elastic flexural strength σ_{fe} (N/mm^2) at the end of the straight portion of the force-displacement curve and the corresponding strains ε_{fM} and ε_{fe}, have been measured. Moreover, the modulus of elasticity in bending E_f (N/mm^2) has been calculated by means of a linear regression procedure applied to the straight part of the stress-strain curve.

Tests have been performed at room temperature on 3 un-strengthened and 3 steel-strengthened specimens. Strengthening has been realized by means of a steel round tube having diameter of 30 mm and thickness of 2.5 mm embedded in the core. Results are summarized in Table 9.

Flexural tests highlight the great deformability of the material. The steel reinforcement has improved both strength and stiffness over than 300% without reducing the ductility (Table 9 and Fig. 12).

Conclusion

Plastics and mixed plastics have been extending their uses and applications due to manufacturing low cost, light weight and durability, so that some traditional materials, such as wood, metals and ceramics have been replaced in some consumer products. Consequently, plastic waste management is becoming a main focus, because recycling alternatives for plastic waste are currently costlier than land-filling and incineration. Mechanical recycling is considered a very efficient solution for plastics.

In this study, the preliminary results of a research aimed at assessing the mechanical properties of a new structural product made of post-consumer plastic waste and known as Recycled Thermoplastic Timber (RTT) are presented. The tested product is manufactured in Sardinia (Italy) and derived entirely from the separate waste collection.

Based on the results achieved since now, the following conclusions can be drawn:

- RTT is a very lightweight material, having a mean density lower than water and it is water proof
- Compressive, tensile and flexural strength and the corresponding stiffness are quite low, if compared to other traditional construction material like timber
- High temperature tests carried out in order to simulate summer conditions pointed out that at high temperature RTT mechanical properties drastically reduce; on the contrary, low temperatures seem to not have significant effects
- Steel strengthening embedded in the core of the RTT profile improves strongly its behavior both at standard conditions and after weathering treatments. No tests have been carried out in order to check mechanical properties of strengthened RTT at high temperature

These preliminary outcomes confirm the potentiality of RTT, also taking into account that the production has a very positive impact on the environment and the material can be used for simple structures, better if joined to strengthened elements.

Further tests will be carried out in order to better exploit the mechanical behavior of RTT. In particular, tensile tests at different temperature conditions, shear tests and the study of durability aspects as the degradation due to UV rays, urban environment, pollution, etc., will be performed. Moreover, theoretical analysis concerning the behavior of the composite steel-plastic section will be developed in order to confirm the possibility of using RTT as a structural material.

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Author’s Contributions

All authors equally contributed in this work.

Ethics

The Authors declare there’s no conflict of interest.

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