A new system for the recovery and the recycling of thermoplastic polyurethanes (TPU) from ski boot equipment

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Every year, 3.5 million pairs of ski boots, equivalent to around 11-12 kton, are produced worldwide, made entirely of virgin materials and subsequently landfilled after three to five years contributing to the alarming plastic pollution. Indeed, because of their complex structure and because of the difficulty of the collection step, ski boots are not yet mechanically recycled (Subie, 2009). From a structural point of view, each ski boot is formed by an external rigid shell which cover the foot, a cuff which connect the shell with the leg, an inner shoe that keeps the foot warm, several metallic buckles, a Velcro strap and the sole (Fig.1) (Colonna, 2013).

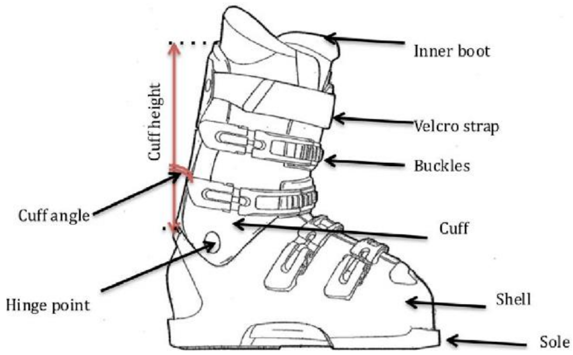

Fig.1 Ski boots component

In terms of materials, the shell is generally made of thermoplastic polyurethanes (TPU) or polyamide (PA), the cuff is made of TPU, the inner shoe is made off pile, polyethylene or, most frequently, Ethylene-Vinyl Acetate (EVA) and the sole is generally a techno-compounded rubber (e.g. Vibram ®). The exact composition of the ski boot mainly depends on the product typology (beginner, intermediate or expert skier) and, of course, on the brand typology. It can be said that intermediate and entry-level ski boots have the shell in TPU (polyester-based) polymers rather than in PA (which is more performant and expensive) and the cuff is made of soft and flexible grades of TPU (stiff cuffs are designed for expert skiers). Since the ski shops rent mostly entry-level ski boots fabricated with the same polymers and since through them the problems connected with the collection of the discarded ski boots could be mitigated or avoided, we have been intrigued by the possibility of mechanically recycling the shells and the cuffs of these sport equipment. Therefore, several ski boots with different lifetimes (virgin (t_0), rented for 20 (t_{20}), 50 (t_{50}) and 109 (t_{109}) days) have been collected and their shells and cuffs have been disassembled and grinded in new pellets. The sorting process has been conducted also in a pilot plant in which the multi-plastics components of the grinded ski boot have been selectively recovered through Triboelectric sorting combined with NIR and magnetic sorting with an efficiency of 95%. In each case, grinded shells and/or cuffs have been subsequently processed by injection moulding to obtain tensile specimens (type 1BA, ISO 527) suitable for thermo-mechanical characterizations.

Recycled specimens have been also aged in lab-scale to simulate the degradative agents such as temperature variation, water absorption, UV radiations and mechanical stresses which may damage the polymer chains of the ski boots during their normal lifetime utilization (Fig.2). Subsequently, recycled specimens have been again grinded and injected moulded with the aim to evaluate how many times ski boots derived TPU could be recycled and used without losing its mechanical properties and melt processability. Degradative contributes due to the reprocessing step and due to lifetime agents have been evaluated both individually and in combination and in each case, the observed properties have been compered with ones of pristine TPU with the aim of ascertain the limits of recyclability and use of the investigated materials.

The obtained results show that, under certain conditions, no significant decreases in mechanical properties are observed up to the 3rd recycling step (Table 1) and that, in most cases, polymer properties are also maintained almost unaltered after many hours of lifetime utilization (Fig.3).

This constitutes a very important and promising information for the recycle of thermoplastic polyurethane used for sport application since it shows that mechanical recycling of pure materials is indeed possible without sacrificing mechanical properties and ski boots performances.
In parallel, the LCA analysis (performed with the software SimaPro following the PCC 2013 GWP 100 method) and the cost analysis (performed with the software SuperPro Designer) of the processes involved for the ski boots recycling have shown how the presented system could represent a cost-effective, eco-friendly and industrially scalable solution.

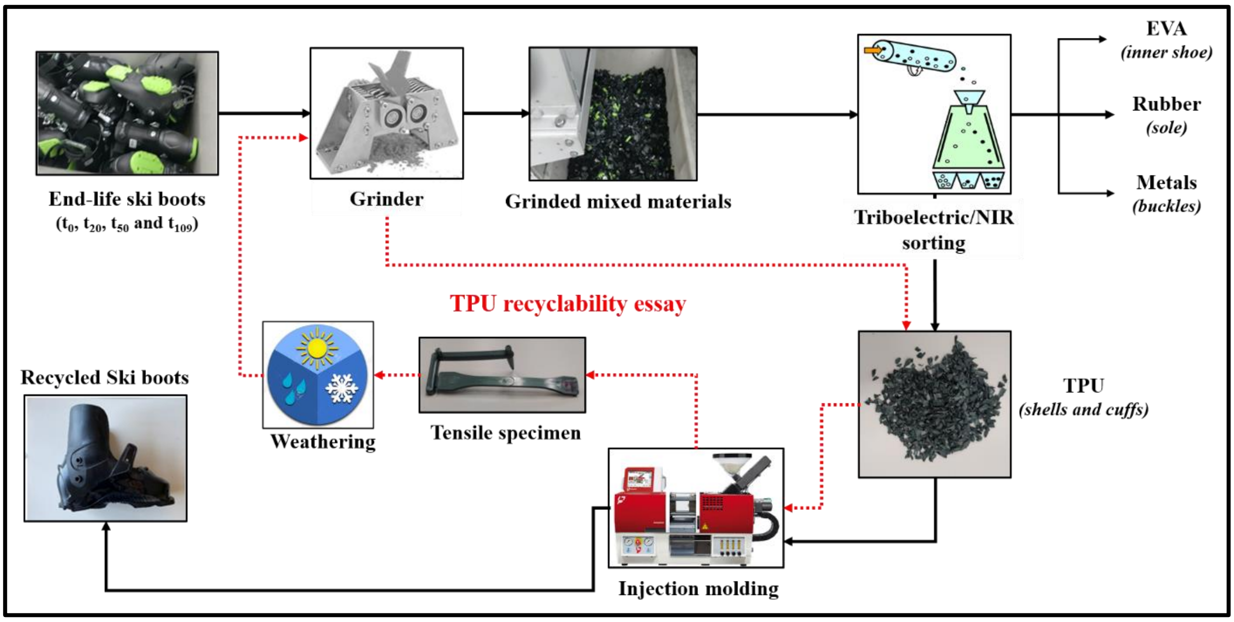

Fig.2 Adopted scheme of work for the ski boot recycling

Table 1: Mechanical properties of pristine (t_0) shells derived TPU after several recycling processes.

Recycling process	Young Modulus [MPa]	Tensile Strength [MPa]	Elongation at break [%]
R1	159 ± 14	44 ± 1	1046 ± 50
R2	161 ± 2	43 ± 2	1143 ± 75
R3	201 ± 9	37 ± 2	1075 ± 80
R4	186 ± 8	26 ± 3	840 ± 155

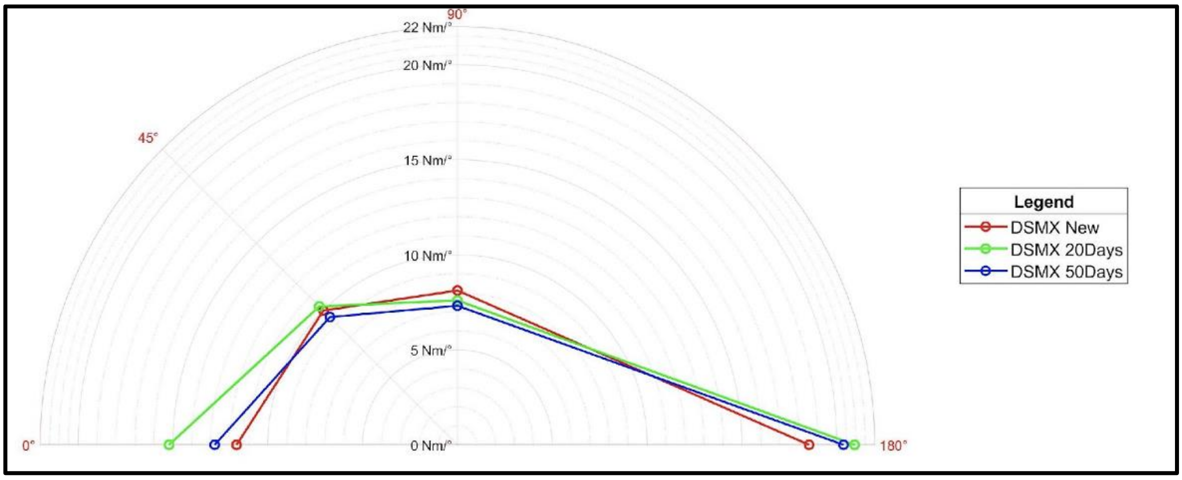

Fig.3 Flexural stiffness at different angles for new (t_0) and used (t_{20} and t_{50}) ski boots.

References

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