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Ageing in athletics tracks: A multi-technique experimental investigation

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ABSTRACT

This is an extensive study of the ageing of athletics tracks, approached with a variety of experimental techniques. The effects of environmental variables, such as UV radiation, relative humidity, water immersion and temperature, were investigated using several artificial ageing protocols, applied to six prefabricated tracks of different color and chemical formulation. A few effective techniques capable of detecting and monitoring the changes occurring in track materials because of ageing were identified among a broad range of available experimental tests. In particular, semi-quantitative colorimetric analysis and dispersive electron spectroscopy were successfully employed to investigate surface degradation phenomena, while uniaxial compression and thermo-gravimetric analysis allowed characterization of the underlying bulk material. The combination of accelerated ageing protocols and monitoring techniques proved to be a powerful tool to study ageing in athletics tracks, with the aim of developing new products with improved durability for installations in critical areas.

1. Introduction

The fundamental role played by modern synthetic surfaces in sport activities is widely assessed: they are extensively employed in several different sports, characterized by having different sets of desired properties. In the case of athletics tracks, the International Association of Athletics Federations (IAAF) provides a list of requirements for approval, involving both their performance and integrity [1,2]. Performance is strictly related to the mechanical behavior of the surface in connection with the athlete. The three most important properties are shock absorption [3], energy restitution and friction [4,5]. The elastic properties of polymers and their excellent capability of absorbing shocks greatly contribute to the enhancement of athletics track qualities, thus guaranteeing the athletes' safety and performance. Shock absorption prevents the propagation of vibrations throughout the musculoskeletal system, preserving it from quick deterioration and possible injuries [6–8]. Finally, the restitution of energy during the propulsion phase, in combination with friction between shoes and track surface, significantly influences the athletes' performance.

Modern athletics tracks can be divided into two main categories: *in-situ* systems and prefabricated tracks. The first includes cast elastomers, resin-bound rubber crumb and composite systems. As the *in-situ* term suggests, the track is produced directly on the field: it can easily adapt to the existing foundation, but it may present some issues of inhomogeneity, especially with respect to track thickness, which may negatively affect the overall behavior [9]. Prefabricated tracks are made by rubber mixtures containing mineral fillers and other additives, which are calendered and subsequently cured; being produced in a controlled environment, they possess more consistent properties in the whole volume. Prefabricated tracks are typically made of at least two different layers. The top finishing one is harder and colored as desired, with surface embossing to improve friction. The bottom layer is often designed with a geometrical structure aimed at adjusting the cushioning ability to the desired level and to respond with different stiffness along propulsion and cornering directions [10].

Tracks of both categories are complex systems in terms of constituent materials, additives and production process parameters. It is, therefore, not easy to predict the effect that material properties have on their final performance. To this aim several numerical models have been developed in the past [11–14].

Given the cost of sport facilities installation, it would be highly desirable that their properties were maintained at an acceptable level over the years. Environment exposure is likely to cause ageing and alter the material's microstructure and properties: as a result, the track behavior will probably change over time. Despite the availability of data regarding installed sport tracks all over the world, to the authors'

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knowledge only scanty research works have dealt with durability of tracks or sports equipment in general; they often concentrate on rather limited aspects, such as mechanical ageing [15] or leaching behavior [16]. The need for a more comprehensive scientific study of tracks durability, able to provide reliable tools for product development and weather resistance verification, motivated the present work. At first, relevant environmental variables were considered, such as UV radiation, relative humidity, presence of water and temperature. The different degradation phenomena produced by each of these ageing factors were then investigated and quantified using various characterization techniques, addressing chemical, physical and mechanical aspects.

2. Materials and experimental methods

The materials investigated in the present study were provided by Mondo S.p.A. (Italy). Six different prefabricated athletics tracks were considered, sharing an identical bottom layer with hexagonal honeycomb structure. The tracks differed in the top (exposed) layer belonging to two main families according to its color (blue and red). Thicknesses for top and bottom layers were about 6 and 7 mm, respectively, for all six materials.

Track labelling goes as shown in Table 1:

Force Reduction (FR) of the samples in their unaged status was measured using an Artificial Athlete (AA) apparatus, according to IAAF specifications [3]; as all of the samples investigated have nearly the same thickness and bottom layer (which is mainly responsible for shock absorption), they all lie in a narrow range of FR values (39–42%) [9].

They all share the same base chemical formulation, a blend of natural rubber (NR), styrene butadiene rubber (SBR) and ethylene propylene diene monomer rubber (EPDM). However, the actual composition and processing parameters differ significantly for the two families of tracks (blue and red), with differences within each family. The six materials were purposely prepared for this study, although there is a certain degree of similarity with existing Mondotrack™ commercial products. Complete tracks were considered, as well as top layers alone, after they were manually separated from the respective bottom layers.

A preliminary study was run on available aged track materials using a broad array of experimental techniques to probe and quantify occurring ageing phenomena, including:

- Image analysis
- Optical microscopy
- Scanning electron microscopy
- Energy dispersive spectrometry
- Infrared spectroscopy
- Thermogravimetric analysis
- Quasi-static mechanical testing (compression, tension, bending)
- Dynamic-mechanical testing (compression)
- Micro-scratching

Some of these turned out to be not effective for various reasons, including poor sensitivity, lack of capability to cover the spatial heterogeneity of track materials, or their inherent complexity. Following these results, only the techniques able to give significant results were used, with the aim of comparing different track behavior and monitor the effects of the considered ageing factors. In particular, image and thermo-gravimetric analysis were carried out on the top layers, while uniaxial compression tests were performed on both top layers and complete tracks. Tests were performed on the reference (i.e. unaged) materials and after each step of the ageing protocols described in section 3, at 250 h time intervals.

Table 1
Sample label, surface color and force reduction value (measured with a Berlin Artificial Athlete).

Surface Color	Track Label	Force Reduction (FR)
Blue	B1	42%
	B2	39%
	B3	40%
Red	R1	42%
	R2	39%
	R3	40%

2.1. Image analysis

Starting from 2D images of the top surface of each sample, collected with a flatbed scanner (*Epson Perfection v33, acquisition at 240dpi@24bit*), a semi-quantitative colorimetric analysis was carried out. Images were analyzed using *ImageJ 1.48k* software, considering separately the red, the green and the blue (RGB) channels; for each one the range was set to between 0 (black) and 255 (white). Readings over the whole surface of each sample were averaged to get arithmetical mean and standard deviation. The channel of major interest was selected according to the top layer's color (blue and red channels for same-colored tracks). Its variation was then tracked during the progressive ageing tests carried out on the tracks.

2.2. Energy dispersive spectrometry (EDS)

In order to investigate the nature of surface ageing phenomena, a semi-quantitative elemental analysis of the surface of samples of a representative material of each family (B2 and R3) was carried out with energy dispersive spectrometry (*Zeiss Evo 50 EP*). EDS allows measurement of the relative amount of a given element on the sample surface; in the present case, elements C, O, Al and Si were considered.

2.3. Uniaxial compression

Uniaxial compression tests were performed using a screw-driven *Instron 1185R5800* dynamometer to obtain information on the mechanical behavior of both complete tracks and top layers. Tests were conducted at 23 °C and 50% relative humidity (RH). The specimens were loaded at a constant strain rate of 0.006 s^{-1} up to a compression ratio of 0.6 (the latter being the ratio between current and initial height of the sample), and then unloaded at the same strain rate. The maximum ratio of 0.6 was selected in accordance with the typical compression experienced by track samples during FR testing, as discussed in Refs. [12–14]. Following those works, specimens measuring 30 × 30 mm in-plane were cut from the full thickness of the complete tracks and from their corresponding top layers.

For each ageing step, two samples from the complete tracks and at least four from each top layer were tested to ensure sufficient repeatability of the mechanical response; in the case of top layers, a larger number was used to reduce potential issues caused by their manual separation.

2.4. Thermo-gravimetric analysis (TGA)

Thermogravimetric analysis was conducted on a *TA Instruments TGA Q500* to investigate the thermal degradation of the track constituent materials and the corresponding weight losses. A suitable program was defined by adapting that typically used for the determination of carbon black content in rubber blends [17]. The following stages were conducted in a nitrogen atmosphere:

a. Heating from 25 to 300 °C at 10 °C min-1
b. Holding at 300 °C for 10 min
c. Heating from 300 to 550 °C at 5 °C min-1
d. Holding at 550 °C for 15 min
e. Heating from 550 to 650 °C at 10 °C min-1