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Position paper

Research and innovation in materials applied to railways

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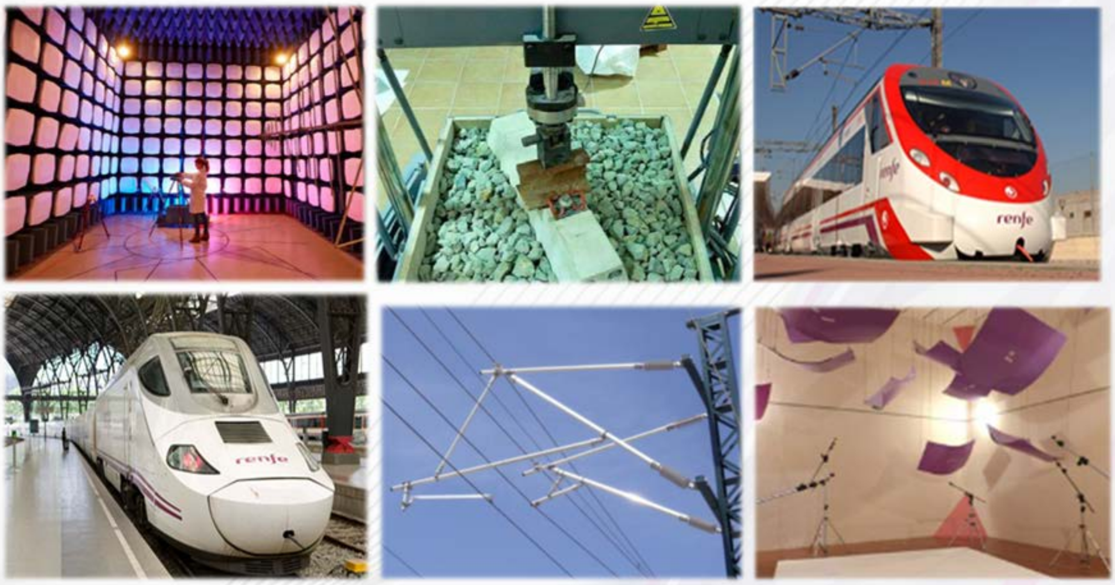

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I. INTRODUCTION

Rail has established itself as one of the most competitive industrial sectors in Spain, with an ever increasing business presence internationally and national projects development. The challenge of maintaining growth and global position has already been met and now the sector should aim to continue its leadership and to harness new opportunities arising from emerging markets.

The sector should aim to build upon its key areas of strength: sustainability, efficiency, safety and security, which calls for greater R&D&I investment by business, research centres, universities and other organizations, such as platforms and associations.

The constant need to overcome the technological barriers of new applications and growing environmental awareness, presents new challenges for the transport sector. New construction solutions and materials are being searched for with a view to decreasing weight, costs, improving recycling processes, and consequently C02 emissions; all of which integrating quality and standards and bringing about standardization.

The use of new materials has been a constant in all sectors, including rail, since the beginnings of its development in the mid 19th Century. The need to employ new materials is ever more important in meeting the growing demands for sustainability and efficiency. This requires rolling stock to be lighter and move on infrastructure able to support greater speeds, loads and passing frequency; reutilization and recycling of materials; and meeting the comfort demands of passengers and those who reside in proximity to the railway line. All of these demands need to be met without reducing system safety.

The Spanish Railways Technological Platform (PTFE) aims to create tools that support the scientific and technological development needed to strengthen the competitiveness, internationalization and sustainability of the rail sector. In this framework and in accordance with guidelines from the Ministry of Economy and Competitiveness (PTFE´s accountable body), it understands that the relevance, development and application of advanced materials, nanomaterials, etc., in the field of rail sector research and innovation, are key factors to strengthening rail industry competitiveness and leadership.

It is within this context that the current “Position Paper: Research and innovation in materials applied to railways”, aims to be at the forefront of development, innovation, future trends and applications in new materials for the different subsectors of the rail system. This strategic document, produced under the coordination of TECNALIA´s Industry and Transport Division and with the participation of business, research centres and research groups from different universities, all PTFE member organizations, brings together a series of challenges and recommendations regarding technologies, materials and specific issues, structured under three headings: rolling stock; platform and track; and facilities.

II. ROLLING STOCK

The presence of faster and lighter trains is leading to greater commercial competitiveness, as well as reducing the contaminating emissions linked to railway transport. These factors, together with improvements in quality, are especially relevant within the context of passenger transport liberalization. At the same time, the standards of comfort demanded by passengers continue to increase.

Greater comfort and passenger space, less weight and cost are somewhat contradictory criteria that demand the development of new materials for structural applications, aerodynamic related aspects and interiors.

On the other hand, the introduction of new materials to rolling stock should take into account those characteristics specific to railways, such as compatibility with the environment, maintenance, reparability and the life cycle of the rolling stock itself. In the same way, solutions that have been successfully tried within other sectors should be reevaluated to verify their suitability for use in rail.

Aluminum has played a key role in railway developments since the 1980s, giving a competitive advantage over steel in terms of lightness, durability and performance in the face of corrosion. In 1996 the TGV Duplex Train provided an increased capacity of 40% with a reduction of 12% in weight[1].

The success of introducing aluminum was possible thanks to innovations in the manufacturing process, such as the development of extruded, large dimensions, hollow sections, the incorporation of new alloys adopted for the aeronautic sector and developments in soldering processes, in which there is still room for innovation, for example, FSW welding (Friction Stir Welding).

Currently there are lines of research open which seek to widen the use of aluminum alloys, not only in structural applications, but also in solid components. This is achieved through semisolid state based technologies which aim to obtain aluminum components with high structural integration, opening the possibility of substituting components currently forged in iron alloys.

Metal matrix composites (MMC) are considered to be one of the greatest developments in materials science in recent years, especially in their application to automotion and aeronautics. Its potential is based on the improved adaptability of its mechanical properties, especially in terms of rigidity, mechanic resistance and resistance to abrasion, as well as the capacity to comply with the strict fire and smoke regulation (EN-144555) enforced in the sector. These types of materials are manufactured using molding or mechanical alloying, a process through which ceramic particles, mainly S_iC and Al_2O_3 of micrometric or nanometric size are added to reinforce.

The latter allow improved properties with a very small percentage of reinforcement. A 1% reinforcement Si3N4P (50nm) achieves a tensile strength comparable to a reinforcement of 15% of SiCp (3.5μm).

Together with metal matrix composites, metal foams present interesting properties, principally due to their lightness and capacity to absorb impact energy and for damping vibrations. For this reason and because of their behaviour when faced with fire and smoke, they are good candidates for applications in structural panels and interiors, floors and the walls of cabins and coaches.

Composite materials of polymer matrix require special attention due to the challenges and implications associated with the process of design and manufacture. These types of materials are usually employed in interior applications and secondary structures. The natural evolution is its utilization in the primary structure of coaches and in other important structural components, following the line of development marked by aeronautics and, more recently, automotion. Railways should draw on the experience from these sectors and find the most suitable approach in relation to cost structures and production. The costs of production make it unfeasible to use the processes of consolidation and curing of pre-pregs in autoclave such as in aeronautics, while the size of components complicate the adaptation to the process of very high pressure infusion used, for example by BMW in their models i3 and i8. In Spain there is already experience in the manufacture of structural components with appropriate properties through liquid infusion processes, vacuum-bag and out of autoclave curing. It is within this framework that a number of activities are planned at a European level, with active Spanish participation, at the heart of the Shift2Rail initiative.

The use of these technologies also requires the development of fiber processing technologies that automate the process of preparation and consolidation for the dry-fiber preforms. These automated processes can achieve properties adapted to areas of greater requirements or local reinforcement, through a mix of different fibers or fabrics or the improved laminates out-of-plane behaviour, through stitching techniques that add fibers in the thickness direction or even 3D preforms that can reach almost isotropic properties.

Some of the most common options for raw material are matrices based on epoxy or phenolic formulations, and their main limitation are the requirements against fire and smoke, which poses the need to turn to fire-resistant resins, modified with additives. With regards to reinforcement fibers, aramid, glass and carbon can be considered, the latter of which having greatest properties.

In the process of design and manufacture of the structural components of new materials it should be taken into account that, in addition to the challenges inherent in the development of these materials, as yet no regulations exist. Different companies and Spanish technology stakeholders are involved in the development of a regulatory framework, as demonstrated through participation in the European Commission REFRESCO project, whose objectives are aligned in this direction.

Furthermore, one of the keys of R&D&I is the multi-material concept, with designs which include the use of more traditional materials such as iron alloys, or aluminum, together with new contributions made by the metal matrix composites (MMC), metallic foams or polymer matrix composites. At the same time, these concepts introduce the need to find a solution to bonding dissimilar materials whilst maintaining the required properties in terms of static and dynamic loads, fatigue or aging and durability.

The Spanish contribution towards developing specific solutions for the high-speed Medina-Mecca line is well known. One of the specific issues is the presence of abrasive particles suspended in the air due to the track running through the Arabian Desert, which has led to the need for a much higher resistance against abrasion. In this context, solutions have been sought in the form of materials based on improved resins and paint coats, its interface with the base metal and also innovative solutions based on plastic-ceramic materials. Surface technology and the development, analysis and improvement of coatings also has a relevant impact on aerodynamics which is ever more critical with the increase of speed, as it is possible to control the separation of the boundary layer in order to reduce aerodynamic resistance.

Finally and regardless of the materials used in the structure of the vehicle, the requirements of weight, cost and especially onboard comfort, entail the use of new solutions and interior materials with improved insulation properties and acoustic and thermal absorption. The seat is one of the most relevant factors in comfort perception. Traditionally these have been manufactured using metallic structures and polyurethane foams. This component is benefitting from the use of new materials, such as silicon or melamine resin based foams, which increase mechanical resistance, reduce weight and improve comfort.

III. PLATFORM AND TRACK

The huge developments in High Speed and the increase of the loads transported by vehicles, amongst other factors, is driving forward the constant evolution of railway infrastructures. This also needs to adapt to growing demands in terms of cost, maintenance and durability, noise and vibrations. The use of new materials to meet these demands is one of the keys of national and European R&D&I programmes, including the Shift2rail initiative.

The key to respond to these demands is the incorporation of elements with adequate elastic and durable properties. Rails, sleepers, track bearing plates, baseplates, under-ballast mat, new ballast compositions, bituminous sub-ballast, are some of the key elements that provide a response to these demands.

Bituminous blends not only improve the vibratory behaviour of the track, but they are also capable of increasing its carrying capacity, stability, resistance to deformation, capacity to protect the rest of the infrastructure or its durability, with reference to the traditional system. Furthermore, it implies a reduction in delivery time and could even signify a reduction in the costs of construction. However, once again the increasing demands for speed, load and frequency make it necessary to revise the solution.

For example, the modification of bitumen through plastomers or elastomers is capable of improving its behaviour and life span. This wide spread solution faces environmental challenges which is driving forward the search for solutions based on re-used materials. Rubber dust from out of service tyres, lamp black or recycled fibre fillings are some of the environmentally friendly solutions that are being proposed.

Bituminous materials can be advantageous for sub-ballast layers. The high density gravel and sand layers have been making way for bituminous solutions manufactured from hot mix asphalt. The behaviour and durability of this type of solution in service conditions are becoming the object of research with the aim of optimizing its design and composition. Furthermore, environment related issues are pushing forward the search for new solutions, based on low temperature asphalt mixes or the valuation of re-used or recycled materials.

The use of these recycled materials and the search for ecodesign solutions, capable of improving the environmental performance of materials and products through the incorporation of recycled plastic materials instead of raw materials, is becoming a general trend. Often the construction of infrastructures, not only railways, is faced with a problem of scarcity of materials, either due to environmental issues or the lack of availability of the material in the required location. The solution of treating and stabilizing floors with lime, cement or polymer can be costly which calls for a search for other more innovative and competitive stabilizing materials, such as pozzolan material originating from residue (CDW[1], slag, ash, glass,…) or wastewater residues, which contain lots of heavy metals; or natural organic materials (micro-binding bacteria). The advantage of using recycled materials extends, for example, to sleepers developed with thermoplastic waste, which are otherwise hard to value.

Tracks set on concrete slabs, increasingly common especially in high speed and the urban environment (trams), have traditionally been run on concrete, which reduces maintenance costs and improves reliability. Currently, there are developments that are helping to overcome issues associated with excessive rigidity and therefore noise and vibrations. These developments are based on the use of bituminous mixes modified with rubber powder derived from out of service tyres, which provide additional shock absorption to reduce transmission.

The growing demand in use also has an impact on the actual tracks whose service provision is being improved. The development of new pearlite, bainite and austenite steels, the application of surface treatments that increase the hardness and resistance of running surfaces, contribute to increasing the service life of the rail tracks.

Rails made from pearlite steel offer in general the greatest properties, whilst severe service conditions, with heightened deformation in the head of rail, a strong abrasion, are driving forward the development of new rails with improved properties (fracture toughness, fatigue, slow crack growth and wear resistance). These new steels are based on thermal treatments, over all the rail and head of rail, in such a way that the pearlite structure obtained presents a finer microstructure, with less interlayer distance; or in the use of microalloyed steel with small quantities of niobium, vanadium and chromium. The objective of these microstructure developments is to gain a material of extreme toughness but at the same time maintaining the contact fatigue.

Other developments, in addition to mechanical properties and durability, focus on the optimization of soldering processes (products which are becoming progressively longer) or the control of the entire manufacturing process, through the use of visual inspection technologies through laser (3D reconstruction) for the detection of surface defects of products at high temperatures.

The reduction of noise and vibrations, as well as the elastic properties of structure and sub-structure components, require the development of new solutions in the form of lighter and less costly materials that can be used, for example, in new acoustic barrier applications that are also harmonious with the environment and landscape.

Noise minimisation can also be addressed through the development of new materials applied to the rail tracks. For example, the OVERRAIL project, financed under the national RETOS programme from the Spanish Ministry of Economy and Competitiveness, seeks the

[1] Construction and demolition waste (translator note).

development of new materials that modify the coefficient of friction, applied on the rail tracks. Finally, the development of new "intelligent" materials whose rigidity and damping properties vary in accordance with the needs at any point during the service, or that integrate new functions, such as the sleepers or bearing plates that are capable of generating energy from the vibrations formed when the vehicle passes over them (energy harvesting), are lines of development with great potential.

IV. Facilities

The catenary, together with other facilities, track and safety elements, are fields in which innovation and new materials play a fundamental role. The need to increase service life under extreme conditions of heat and humidity, the wear caused by wind suspended particles and actions derived from the wind, together with the reduction of costs associated with facilities and maintenance, are factors which justify the application of new materials in rail system structures and facilities.

Facilities sometimes need to be constructed in places with difficult access. Furthermore, the complexity of these types of operations can increase considerably due to the unavailability of equipment in the area needed to facilitate the installation. In summary, the overhead line, poles, cantilevers and registration arms are, at times, parts which are complex to transport to the site of installation both due to weight and dimensions.

It is possible to resort to alternative materials that, as well as delivering the necessary benefits, are lighter in weight and facilitate transportation, approach and assembly. Polymer-matrix composite materials profiles offer excellent characteristics in terms of lightness and resistance in extreme environmental conditions of hot and cold, humidity or solar radiation. The manufacturing of these profiles through pultrusion techniques is a highly competitive solution, with the processes of manufacture and paint automation being the object of a number of R&D projects. There are also developments in registration arms in polymer-matrix composite materials and these materials are also supporting improvements in the life cycle of insulators. Other components, such as poles, could also be improved through the use of these materials.

The phenomena related to the contact between the catenary and the pantograph has always been a focus of research and development, due to the problems of mechanical wear and the requirements of electrical properties. New materials can contribute towards increasing service life under adverse meteorological conditions. In this way, the objective of tribological studies of materials has been performance improvement, minimizing energy loss and wear. Traditionally these studies have been limited to electrolytic copper (ETP), with alloys such as Cr, Zr, Ag y Mg or graphite.

These studies can be extended to include variables such as the degree of humidity or the salinity or the parameters of thermomechanical copper treatments. Furthermore, as alternatives to electrolytic copper, new poly micro-alloys have been developed with higher temperatures of recrystallisation and improved mechanical properties, which provide greater resistance to wear and low temperature creep.

Less wear decreases maintenance costs and a higher annealing temperature increases the capacity of the contact wire to bear peaks of intensity. The contact between the catenary and pantograph can be improved through using shock absorbing materials in the supporting structures, in such a way as to minimize the stress and wear.

With regards to the effects of wind action, there are areas of R&D related to the development of materials and coatings capable of withstanding the abrasion caused by suspended particles, as well as registration arms and cantilever tubes of greater rigidity and resistance.

Finally, the use of fibre-optic should be highlighted as a tool to monitor the facilities, not only in the infrastructure but also the catenary and cable conduit. Spain, Germany and Japan are actively working in this field.

V. CHALLENGES AND RECOMMENDATIONS

In summary, railway transport is growing thanks to the advantages of this transport mode relative to competitors. Consolidating this competitive advantage in a context that demands greater speed; lower construction, maintenance and operation costs; greater loads per axle; and more frequent running, requires the continued strengthening of research, development and innovation. Continued knowledge transfer between the aeronautic, naval and automotive sectors and civil engineering or industry sectors would be expected, as has historically taken place. However, whilst in other sectors innovations in materials provide steady improvements, the majority of railway systems continued to be based on traditional materials.

Polymer-matrix composite materials are now common place in civil engineering works, as reinforcement to structures or in the construction of bridges. Self-healing concrete and biomaterials are also examples of innovation in the construction sector. Carbon fibre, new ceramic materials, grapheme and /or silicone are becoming substitutes for steel and metals used in the aeronautic and automotive sectors.

The introduction of these and other new materials in the railway sector should be based on the knowledge and experience acquired in other sectors, whilst taking into account the cost structures and specific demands of railway applications. Furthermore, growing social awareness regarding respect for the planet ensures that new materials are developed in line with concepts of sustainability, reuse and recycling. The majority of the innovations described in the section on platform and track, fit into this framework, which, furthermore, presents an area with huge innovation potential. In fact, there are a great number of materials, either natural or artificial that can be used in the construction of railway infrastructures. However, normally solutions used in the construction of roads cannot be applied to railways, or at least not in all countries, as they are not considered in the regulations and they are not harmonized, not even at a European level.

Regulatory aspects are also fundamental with regards to the use of new materials in the area of rolling stock. A clear example is the restrictions introduced by the rules on behavior in fire and smoke (EN- 45545)influencing the introduction of new materials The existing regulation has been focused on guiding the development of vehicles based on traditional materials, which means that there are new materials which are not considered or applicable. Design criteria, safety margins, calculation methodology, safety regulations, recyclability and the process of homologation, amongst others, are points that the regulation needs to develop in order to facilitate the use of new materials and to accelerate the technological development of the whole sector.

With regards to the actual track, the challenge faced by manufacturers is the increase in its service life under service loads, products with greater fracture toughness, slower fatigue crack growth and greater resistance to wear. In order to obtain these improvements, it is necessary to have technological capacity applied to the study of microstructures, thermal and mechanic treatments, the characterization of the fracture toughness, speed of crack growth or tribological testing. Other aspects are the development of the more efficient solder technologies, which aim to reduce the levels of residual tensions and the microstructures desired, the use of laser to modify these structures at a superficial level (hardening laser) or laser deposition.

By way of conclusion, other identified needs include:

- Training of engineers and designers with the development of a more flexible design methodology and knowledge of the possibilities and limitations of new materials.

- Closer collaboration through programmes, between all stakeholders: administrators, manufacturers, companies, technology centres and universities.

- Strengthening of technology transfer from other sectors, such as civil construction, aeronautics, automotive or the industry.

- Coordination of work in order to avoid duplication, for which the PTFE will play an important role.

- Have available test routes and facilities to undertake real scale trials of new materials for infrastructure, facilities and rolling stock.

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