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NOISE-RELATED ROUGHNESS ON RAILWAY WHEELS GENERATED BY TREAD BRAKING

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ABSTRACT
Freight trains are usually equipped with cast iron brake blocks, which cause roughness on the braked wheel surface, and consequently, high levels of rolling noise. The project Eurosabot aimed at developing a brake block that should suppress the formation of wheel roughness, whilst still providing the required braking performance. A scientific approach was followed: try to understand measurement results, build models, generate solutions supported by the models and the increased understanding, select the most promising ones and test prototypes. This paper summarizes the major findings of the Eurosabot project.

1 - INTRODUCTION
In most European countries railway noise is submitted to legal restrictions or limitations. If the train intensity is further raised, compliance with legal limits can only be achieved if the noise creation is reduced at the source. The main noise source, rolling noise, has been significantly reduced over the last decade, thanks to the large scale introduction of disk brakes in passenger rolling stock and the common usage of continuously welded rail. For freight traffic, however, a similar development has not occurred and is not expected to occur in the near future, mainly because of the strongly international character of freight traffic. This has led to UIC (International Union of Railways) specifications regarding standardisation and interoperability of the block brake system, based on the characteristics of cast iron as block brake material.

Cast iron has many properties that make it a suitable brake block material, but it causes roughness on the wheel tread, and consequently a high level of rolling noise. For this reason the Brite-Euram project "Eurosabot" was started to develop a brake block material for freight vehicles that should suppress the formation of wheel roughness, whilst still providing the required braking performance.

2 - THE EUROSABOT PROJECT
The "Eurosabot" project was started in 1995 as a Fourth Framework Brite Euram research and development project. The project objective was to find low cost solutions, suitable for retrofit application and available in short time after completion of the project, that would assure a significant reduction of wheel surface irregularities (roughness) and thus lead to a significant reduction of rolling noise (5 to 8 dB(A)). The consortium consisted of researchers (universities and consultancies), manufacturers and suppliers of brake blocks and wagons, and end users (four railway companies).

A rather classical R&D approach was followed: first study phenomena and formulate hypotheses to explain the observations; then build and validate a model based on the hypotheses; then generate solutions and select the most promising ones on the basis of the model and experiments; then demonstrate the efficiency of the solutions by prototype testing. An overview of the project is given in a public report [1].

3 - OBSERVATIONS
From the beginning it was felt that both thermo-elastic instabilities due to local heating of the contact surface, material transfer between block and wheel, dynamic instabilities and wear are responsible for the generation and growth of wheel roughness, often with a remarkable periodic character. In an early stage of the project a series of dynamometer tests were held under controlled conditions, aimed at identifying

the phenomena involved and the parameters responsible for roughness growth. These tests were carried out with cast iron, composition or sinter brake blocks on the wheel. In addition, initial field tests were organised to provide a clear insight into the influence of the various operational conditions on brake performance, adhesion of powered wheels, generation of wheel roughness, rolling and braking noise.
The lab and field tests consistently resulted in a considerable increase in knowledge on the phenomena involved in the generation of wheel roughness on tread-braked train wheels. However, it appeared to be very difficult to validate all causal steps of the postulated roughness generating mechanisms. Apparently, there are too many phenomena involved, interacting in a complex and unknown way. For instance, no evidence has been found to validate any roughness generating mechanism based on vibrational instability.
The tests give answers to the question why traditional cast iron brake blocks generate wheel roughness, and why composition and sinter blocks in general do not. The initiating phenomenon for roughness generation with *cast iron* brake blocks is *thermo-elastic instability* (TEI). Initial non-uniformities in the contact area between the block and the wheel tread result in a local heating and thermal expansion, yielding *hot spots* with very high temperature (500°C or more) on the wheel tread. The hot spot formation results in a wear regime called *galling*, characterised by welding together and separation of the surfaces and transfer of block surface material to the wheel surface. The galling process is self-aggravating. It is stabilized by wear; however, cast iron blocks are not abrasive enough to wear the transferred spots off the wheel again. Both hot spot formation and galling are threshold events; therefore, the roughness pattern found on wheels is formed during stop braking with high thermal power [2].
Composite blocks form a more regular contact area and, consequently, less severe hot spots, partly because of the flexibility of the block, partly because transferred block matrix material fills the "valleys" between asperities on the wheel surface. However, composite blocks have some important drawbacks: they impose high thermal loads on the wheel, possibly resulting in thermal cracks and spalling; the adhesion between wheel and rail is worse, and the brake performance in wet conditions is strongly different from dry conditions.
Sinter blocks are abrasive to the wheel. During braking hot spots are formed, but no roughness pattern grows, because protrusions on the wheel surface are immediately worn off. From the maintenance point of view, the abrasiveness of sinter blocks is a drawback.

4 - MODELLING

Based on the validated hypotheses and mechanisms, numerical models were built to improve the understanding of the mechanisms of roughness development, to study the main parameters of influence, and to support the design of new solutions. However, there were a number of obstructions that seriously prevented these objectives from being reached. The most fundamental one is the complexity of the problem: there are many phenomena involved that interact in a complex way. There are three categories of phenomena involved with strongly different time scales: vibrations, thermo-mechanic and wear phenomena. Combined with the enormous model size of each submodel describing only one aspect of the system behaviour, the combination of all models into a comprehensive model could not be realised in the project.
The modelling studies have produced a set of useful research tools that each give an insight into the main processes involved during braking operation with regard to the growth of wheel roughness. This set consists of three models describing the thermo-mechanical behaviour, three wear models and one dynamic model. More details on the models and a benchmark study are given in [1 − 3].
Despite the successes in modelling, still a significant need is felt for further development, mainly to understand the complex interaction between thermo-mechanical, dynamical and wear behaviour of the wheel and the brake system. Besides, there appears to be a need for a suitable cheap and fast method allowing the industry to assess the value of a number of input material properties as a function of engineering decisions, before the models can be used as an optimisation tool.

5 - SOLUTIONS

New brake block solutions have been developed, aimed at a block brake prototype to be tested in a final field test. In a first stage, solutions were generated following both brain storming and systematic approaches. A creative brain storm session resulted in ten promising ideas. The main observations in the initial tests yielded directions for solutions, such as: find a sinter material that is less abrasive. Besides, design criteria for new solutions were derived from a market characterisation. A first selection resulted in nine promising principle solutions.
In a second stage, 18 samples of new designs were manufactured and tested on a dynamometer. The performance of each design was judged along six criteria: wheel roughness generation, cost, wheel wear

rate, thermal load on the wheel, brake performance in wet conditions, and squeal noise generation. The wheel roughness was judged using an acoustical roughness indicator [4]. The six most promising designs were selected for further testing.
Next, these six designs were tested on the stability of their braking performance under a wide variety of operational conditions. A dynamometer test procedure was devised, based on the normal UIC qualification protocol. Four block designs were selected for the final field test campaign: two composition blocks and one sinter block for low roughness generation and stable brake performance, and one cast iron multi-block design with elastic block mounting with reasonable performance, being the only candidate suitable for retrofit applications.

6 - FINAL FIELD TESTS

The final field tests were organised to verify that the prototype solutions would indeed yield a rolling noise reduction due to a lower wheel roughness and that they would meet the main functional requirements. The test programme included initial brake distance tests, endurance tests, and parametric tests including roughness and noise measurements.
The cast iron multi-block broke down due to manufacturing faults. Besides it produced much brake noise and incipient corrugation. One of the composition blocks showed excessive block wear and excessive hollow wheel wear. This was probably caused by metal pick-up in wet and cold winter conditions. The other composite block completed the field tests, but only a modest noise reduction ($2-5$ dB(A) relative to cast iron braked trains) was realized. The sinter block completed the field tests and realized a noise reduction between 3 and 6 dB(A).
Besides yielding these results, the field tests have raised questions on the reliability of the process of rig testing. The roughness measured in the field was much higher than on the test rig, as can be seen for the two composition blocks in Figure 1, where the dB scale of the roughness is proportional to rolling noise. The failure of one of the composition blocks, was unexpected: the blocks successfully passed the qualification tests based on the UIC protocol.

7 - CONCLUSIONS

Thanks to the scientific approach in the Eurosabot project, the understanding of the processes that are important in wheel roughness generation by cast iron train block brakes has been significantly improved. In addition, great advance has been booked in the modelling of thermo-elastic instability and combined dynamic-thermal-wear instability. However, the project did *not* succeed in identifying a "low roughness" brake block material suitable for a simple retrofit exchange of cast iron blocks. Two new block materials, a composite and a sinter block, passed all tests but showed a disappointing noise reduction potential of about 4 dB(A). The unexpected failure of a prototype block in the field tests and the deviation in the wheel roughness growth between the lab and the field tests have raised questions on the reliability of the admission rig tests for brake blocks.
It is recommended to base the continued search for a retrofit brake block design on the improved understanding and modelling, rather than on trial-and-error. Besides, the rig test procedure used for admission of new brake block needs to be evaluated.

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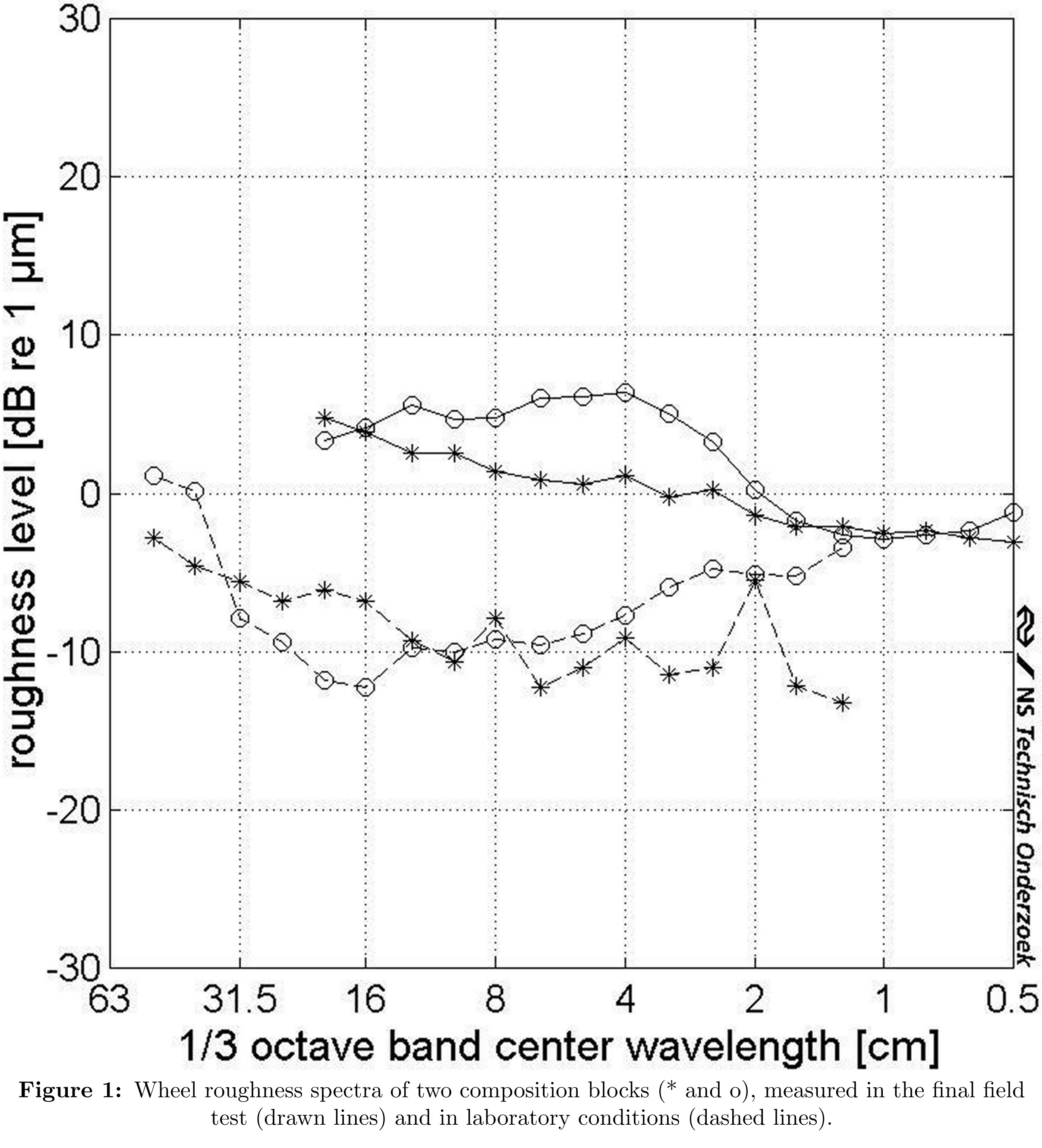

Figure 1: Wheel roughness spectra of two composition blocks (* and o), measured in the final field test (drawn lines) and in laboratory conditions (dashed lines).