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"Recent Developments of the Asphalt Industry."

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Since 1880, when a Paper[1] by the Author on "The Use of Asphalt and Mineral Bitumen in Engineering" was read before a meeting of the Institution, the employment of the material has so largely increased that it may be worth while to take a retrospective view, and a glance into the future of this industry, in which so much British capital is invested, and the development of which gives employment to so many engineers.

Asphalt is a natural product, and consists of limestone impregnated with pure mineral bitumen. Its ideal composition is 80 per cent. to 90 per cent. of pure carbonate of lime, and 10 per cent. to 20 per cent. of pure mineral bitumen. Bitumen is natural mineral pitch, composed of 85 per cent. of carbon, 12 per cent. of hydrogen and 3 per cent. of oxygen. It is only found pure in the rock which it permeated when in a state of vapour, and under enormous pressure. The recent eruption of Mount Pelée, in Martinique, affords evidence of the great heat and pressure caused by the combustion of bituminous vapours. Mineral bitumen should not be confounded with the residuum of crude petroleum, naphtha, shale, or animal fats, nor, above all, with gas-tars: these contain dyes, which natural bitumen does not. As asphalt and bitumen are natural products, they vary in quality and must be taken as Nature produces them. Thus the limestone in the Sicilian variety of asphalt is of coarse grain; but in Seyssel, Val de Travers and Servas asphalts the grain is fine, so that the specific gravity of Sicilian asphalt is less than that of the other rocks named. The bitumen contained in Seyssel and Sicilian asphalts is solid and tough, whereas that contained in Val de Travers asphalt is oily.

The Author, having experienced much trouble due to waves and buckling in roadways of Val de Travers asphalt under heavy traffic and exposure to hot suns, consulted the late Mr. Schützen-

[1] Minutes of Proceedings Inst. C.E., vol. lx. p. 249.

berger, Professor of Chemistry at the Collège de France, who had made a special study of hydro-carbons. This eminent chemist, after separating the bitumen from the pulverized rock by dissolving it in carbon di-sulphide and filtering the solution, heated the bitumen *in vacuo* without obtaining any appreciable evaporation; when the heat was increased the bitumen decomposed. This showed that the oil could not be got rid of by heat, and led the Author to blend Seyssel with Val de Travers, and subsequently with Servas rock, with satisfactory results. By blending, asphalt powder for roadways can be obtained suitable for tropical or temperate climates.

The molecules of natural asphalt are held together, not by cohesion, but by bituminous agglutination. Mr. Léon Malo found that the test for asphalt is to heat a small piece on a hot iron plate, when it will fall to pieces. To test its compressibility, a small hydraulic press with appropriate moulds, or a tube with a plug and hammer, may be used. Some asphalts, after being subjected to a pressure of 6 tons per square inch, will crumble under pressure of the fingers. The unimpregnated limestone found in an asphalt mine will not crumble on being heated.

Asphalt mastic is composed of asphalt powder and refined bitumen, mixed mechanically in a boiler under heat. The mixture, after being heated to, say, 400° F., is run into moulds, the blocks weighing about 56 lbs. It should contain about 15 per cent. of bitumen, native and added, and will not fall to pieces on being heated, as asphalt rock does, nor will it compress. Mr. Malo has pointed out that in a layer of compressed asphalt the top of the layer is always denser than the bottom, even when the thickness has been reduced by wear to $\frac{1}{2}$ inch. The surface, therefore, always rests on a cushion. To make good mastic, care and experience are required. It must be made of blended rocks, ground very fine, mixed with refined bitumen and thoroughly cooked; it cannot be too pure. For footpaths, grit is added to it, say, 33 per cent. for temperate, and 50 per cent. for tropical climates. Clay, pyrites and vegetable matter are all detrimental, whilst taking up the place of good material. The qualities of asphalt, bitumen, and their product, mastic, are remarkable, and are daily being more and more appreciated in engineering work.

Asphalt makes noiseless roadways, is impervious to water, and produces no dust or mud; mastic makes footpaths like a carpet, arrests capillarity, is air-, water- and vermin-proof, absorbs vibration and is a non-conductor of electricity. By mixing bitumen with pure silex, a mastic can be made which resists acids.

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The Island of Sicily alone now produces annually 75,000 tons of natural asphalt, sufficient to lay 812,000 square yards of compressed asphalt, 2 inches in thickness; whilst the output of the other mines in Europe (Seyssel, Val de Travers, Chieti in the Abruzzi, Limmer, Vorwohle, Lobsann, Auvergne and Syzrane in Russia) may be estimated at 120,000 tons annually; whereas previously to 1870 the Seyssel and Val de Travers mines were the only ones of repute, and their combined annual output was about 50,000 tons. When in the United States some 5 years ago, the Author noticed that one American Company, managed by a Colonel of Engineers, had an army of 18,000 men employed daily in laying bituminous compounds for roadways in different towns of the Union. Often the process followed was to construct the roads first, and to build the towns afterwards; where money was not available, payments were effected in bonds on land, or even on produce. The Author's experience has been acquired chiefly in France, where the asphalt industry originated, and where the special plant and tools, now used everywhere, were invented and elaborated.

In 1872 the Author was called upon to undertake the management of the original Asphalt Company, which had the contract for all the compressed asphalt roadways for the town of Paris. These roadways were then being laid on hydraulic-lime concrete, only 4 inches in thickness—actually the same thickness as for footpaths—and of this ½ inch thickness consisted of a mortar floating, spread upon the concrete after it had been laid, which crumbled under the blows of the rammers used in ramming the hot asphalt-powder to make the road. On the Author's recommendation, Portland-cement concrete was laid, at the Company's expense, in the Rue d'Antin, and this work stands to the present day; the old streets, however, were all laid on lime concrete. Some of the engineers of the town of Paris who had the superintendence of the works declined to have Portland-cement concrete at any cost, and at the end of 5 years, when the concrete wore out, the Company had lost £40,000, owing to the onerous conditions of the maintenance contract, by which they were paid 1 franc per square metre per annum for all repairs, including the re-laying of one-tenth of the surface annually and setting the whole in order at the end of the contract. When holes in the asphalt had to be repaired, the crumbling concrete had to be re-laid also, but, owing to the exigencies of traffic, it had not sufficient time to set, so that work was carried out under grave difficulties; and in rainy weather, in order to get a dry surface for the hot powder, it was necessary to use bituminous concrete, or at least a layer of liquid asphalt.

In general, yielding materials like asphalt require a rigid and resisting concrete, and floating is undesirable. Finding how detrimental to the asphalt roads was the greasy mud brought from macadam and stone pitching, the Author presented the town of Paris with one hundred india-rubber squeegees, and this led to the adoption and manufacture of these tools in France. He also designed a special form of water-cart for cleaning asphalt roadways, the sprinkling being effected in front of the horses, as well as behind them, the French plan of flushing with a fireman's hose and nozzle being impracticable in narrow streets or in windy weather. The extreme gradient for an asphalt roadway is 1 in 30, and the camber between the outside edge of the gutter and the crown of the road should not present gradients of more than 1 in 50.

In 1884 the town of Paris made a 10-years' contract with the Author's Company, by which they agreed to pay, for a 2-inch layer of compressed asphalt, 14 francs per square metre (9*s.* 4*d.* per square yard) and for a 6-inch layer of Portland-cement concrete 5½ francs per square metre (3*s.* 8*d.* per square yard), and for maintenance 2 francs per square metre (1*s.* 4*d.* per square yard) per annum, with the undertaking that all the streets laid with lime concretes should be re-laid with Portland-cement concrete, the town paying for the repairs on those streets apart, until the substitution should take place. It was in 1884 that Sicilian asphalt was accepted for the first time, the Paris Engineers having been commissioned to visit and report on every asphalt mine then known, and it took the place of St. Jean de Marvejols asphalt, being cheaper. A branch of the London Limmer Asphalt Company obtained the contract for about one-third of Paris, but afterwards passed over their contract to a French company, formed by the Neuchatel Company, Limited, which holds the concession for the Val de Travers mines, who had not renewed their concession to the Author's Company. It is notable that English capital had absorbed the asphalt industry originated in France, and led to its development all over the world.

The town of Paris allowed the contractor to grind up the pieces of old compressed asphalt from gas trenches and repairs, and to convert it into mastic for the liquid gritted asphalt footpaths; but it would not allow the old gritted mastic from the footpaths to be used again for new works or re-layings; this could only be used for small repairs and trenches, and even then only if mixed with an equal quantity of new material. The area of the asphalt mastic footpaths in Paris is about 6,000,000 square yards; this material provides a surface which is less fatiguing to walk on, and much more agreeable to the sensitive human foot, than granite, stone, or hard cement. The town paid 35 centimes per square metre (2·8*d.* per square yard) per annum for the maintenance of the footpaths, laid 15 millimetres ($\frac{9}{16}$ inch) in thickness, for all repairs arising from wear and tear, including the re-laying of one-fifteenth part of the entire surface every year, whether wanted or not. The thickness of the layer being 15 millimetres, and the wear of the surface being estimated at 1 millimetre per annum, it was supposed that at the end of 15 years the whole surface would be re-laid. In practice, however, it was found that the narrow streets in the centre of the town wore out in 5, 6, or 10 years, owing to the heavy traffic, whereas those in the suburbs were as good at the end of 15 years as on the day they were laid. Knowing that old mastic, remelted with fresh bitumen (the main ingredient of asphalt), is just as good as, if not better than, new mastic, owing to the second fusion, the Author proposed to lay all surfaces 20 millimetres ($\frac{3}{4}$ inch) thick, instead of 15 millimetres ($\frac{9}{16}$ inch), using a mixture of equal quantities of old and new mastic, already admitted for repairs and trenches, and to suppress the obligation to re-lay one-fifteenth part of the surface annually, only re-laying what was necessary, thus saving annoyance to householders and unnecessary carting, whilst the contractor got rid of materials easily that otherwise he had to sell to suburban corporations, private undertakings, etc. The proposal was agreed to, and this arrangement has been continued ever since, to the general advantage of all concerned. The concrete used with compressed asphalt prepared in this way is composed of washed flint pebbles, river sand, and best Portland cement, gauged 4, 3 and 1. The cement, not more than 2 months old, is first turned over dry, then mixed wet, being sprinkled just enough to hydrate it. No floating is required. A level surface is obtained by using a straight-edge and smoothing the mass with a flat rectangular shovel, filling up any cavities with a little mortar, composed of 3 of sand and 1 of cement, mixed on the spot. By this plan the whole mass sets at the same time, which is absolutely necessary for hot asphalt-powder, whereas for wood or cold asphalt slabs this is not necessary. It is well to allow 5 days for setting in summer, or 7 days in winter, and the surface must be dry, otherwise the powder, heated to 300° F., would convert any moisture into steam, which, in passing through the asphalt, would give rise to nodules. For liquid-asphalt footpaths, hydraulic-lime concrete may be used, and a mortar floating, in order to get a true surface with a straight-edge, and to prevent more asphalt being laid than the thickness warrants. A $\frac{3}{4}$-inch layer weighs 80 lbs. to the square yard.

Perhaps the best method of protecting any work in masonry, or iron vaults, roofs, reservoirs, etc., is by means of two layers of pure asphalt, $\frac{2}{5}$ inch in thickness, superposed, the joints of the first layer being covered; a recess can be cut into the masonry and the fillet pressed in. Such a layer will weigh about 68 lbs. per square yard. A damp-course laid in walls of buildings, at a level of about 1 foot above the ground, will stop capillarity and preserve the buildings from the action of water and frost. To keep out damp is as much a necessity of hygiene as good drainage. The Egyptian Sphinx, the Pyramids, and so many tombs and buildings, not to mention more recent Roman buildings in Africa, have survived mainly because the chief elements of decay, water and frost, are absent; if such constructions had been in England, the expansion caused by frost and the contraction caused by thaw would speedily have disintegrated them. In many brick and stone railway-arches in Paris, water drips through the joints after prolonged rain. The Pont du Jour, a stone viaduct over the Seine at Auteuil, is full of water in rainy weather, and from certain joints water runs out as from a spring. Mr. Barabant, the Manager of the Eastern Railway of France, who, as Ordinary Engineer, and subsequently as Chief Engineer, of the town of Paris, had special opportunities of studying asphalt—having had the Municipal Laboratory under his charge—has had all the bridges and viaducts on the ordinary and strategic lines between Paris and the frontier laid with pure asphalt coating, and has had the platforms of the Paris and Nancy stations laid in compressed asphalt slabs and powder. The Paris Lyons and Mediterranean, Orleans, Midi, North and West Railway Companies have largely used Seyssel asphalt for platforms, bridges, viaducts, etc.

It has been abundantly proved that asphalt mastic is unaffected by cold or heat, *i.e.*, expansion and contraction do not alter its qualities. The late Captain Coignet had some of the Seyssel asphalt coating from the bomb-proof casemates of the Donjon of Vincennes taken up, after lying entombed since 1833, and found that no change had taken place in the asphalt. A root of lucerne, 5 to 6 yards in length, had tried in vain to penetrate the layer. Asphalt has the defects of its qualities, for in foggy weather the moisture in the atmosphere will condense on the asphalted surface of the casemates, and must be swabbed off. This is better than letting it soak into an ordinary soil. But, for this reason, in asphalted railway-stations, flour, cement and lime must be kept off the ground by wooden frames. The gradual disintegration of walls and floors is sometimes traceable to the ravages of rats and mice; they will nibble through concrete, but they leave asphalt alone. Being a non-fermenting and non-decaying material, it affords no home to insects. A floor laid on joists fixed on liquid asphalt is safe from vermin, and there need not be any appreciable space between the asphalt coating and the upper flooring. In the case of fire, asphalt keeps out the air, and holds water; when the wood-work below it has been burned away, it will fall like a wet blanket on the flames and extinguish them. This quality was proved by the experiments made by the Omnibus and Cab Companies in Paris, with the result that the floors of granaries and silos, wash-houses, stables and mangers are now generally coated with liquid asphalt. It was found by Messrs. Tourtel Frères, of Tantonville, near Nancy, that whereas gas tar gave a disagreeable flavour to malt, natural asphalt was absolutely neutral; this has led to its adoption for flooring in many breweries and maltings. Slabs of asphalt of various sizes and thicknesses, made in a hydraulic press, are now manufactured largely and sent to all parts of the world. They are laid on Portland-cement concrete similarly to asphalt powder, but are fixed in a wet layer of pure Portland-cement mortar; after being laid, cement grout is poured into the scarcely-perceptible joints, and swept off with saw-dust when dry. These slabs stand well in streets and courtyards where there is little traffic, and require no costly plant, as does powder; they can be laid on wet concrete, but, as they have attained their ultimate compression, wear begins at once.

A method of laying asphalt powder cold, by mixing it with petroleum essence and a solution of india-rubber, which softens the bitumen contained in the rock and so facilitates compression, the petroleum afterwards evaporating, has been recently employed in Marseilles, Antibes, Barcelona, Aix-les-Bains, Toulon, Nice and St. Etienne. By this process work can be done in rainy weather.

Just as plasterers mix cow-hair with their plaster, and as cement is strengthened by iron wire and rods to give it tenacity under strain, so liquid asphalt can be treated for making tanks, pipes, conduits, reservoirs, etc. Asphalt, and india-rubber, of which it is a counterpart, are both hydro-carbons, having the same ingredients. Asphalt has little resisting power in itself, but it can be laid on a hempen sheet or thick paper, to give it more tenacity as when laid upon a wood flooring. When liquid asphalt is used for the inside lining of a reservoir, vertically, a layer of brick should be laid in front of it as the work proceeds, to keep it up. In Germany, cement tanks for holding molasses are now being replaced by asphalt, which does not crack. Bitumen resists alkalies and acids, so that by mixing it with pure silex in powder, or with pulverized basalt, a mastic or paste can be made which can be applied like ordinary mastic for accumulator-rooms, baths for electrolysis, etc.; numerous special applications of this material have been made for the Electric Traction Company at Paris, Lyons, and elsewhere. It has been found that the large Portland-cement-concrete blocks used in connection with breakwaters and piers to arrest the force of the waves, become disintegrated by the action of the magnesia in the sea-water, as well as by the boring propensities of numerous marine animals. The blocks may be protected by an application of liquid asphalt, say $\frac{9}{16}$ inch thick, upon each side of the cube, carefully jointed at the angles, and the remedy, though expensive, is sure. Asphalt flags are made by running mastic in shallow moulds on a true-planed cast-iron slab; they are laid on a concrete base, the joints being run with a little special mastic, heated in an iron basin and spread with an iron tool. At the works of the Compagnie Générale des Asphaltes de France, the strong-room is made of bituminous concrete, and is absolutely fire-proof. Pipes and tubes can be made for the carrying of telegraph-, telephone- or power-wires. Bitumen resists the corrosive action of acetylene-gas on iron pipes; and in Paris, water-pipes are coated with a layer of mastic before being laid in the ground, thus preventing external corrosion.

The chief application of asphalt to which the Author desires to direct attention in this Paper, however, is its use as a material for absorbing vibration, either caused by the passage of trains and heavy vehicles, or by percussion, like that of the steam-hammer, and also as a foundation for heavy ordnance in forts. Mr. Malo, at the Seyssel mines, first experimented on these materials, and his lead has been followed up by the Author. The material used may be either bituminous concrete, or asphaltic powder, as used for roadways; the powder, however, must be rammed in successive layers in a suitable case or box, made of steel or wrought iron, to support and maintain it, and the layer, instead of being 2 inches thick, is 8 inches to 1 foot in thickness. Asphaltic powder is used chiefly for foundations for steam-hammers, the bed-plate fitting on to the asphaltic mass. There are numerous examples of its use, and no failure has been recorded. In the year 1872 the Author had at work a Carr disintegrator, making 700 revolutions per minute, for grinding rock-asphalt, the axles being supported on stout oak bearings. The vibration transmitted through the soil was such that it was quite impossible to write within 600 feet of the machine. Being threatened with a law-suit, he resolved to put down bituminous concrete foundations for the bearings, and to surround the pit in which the machine worked by a wall of the same material. When the work was completed, no one could tell in the adjoining workshops and warehouses whether the machine was working or not, and a glass of water placed on the bituminous concrete wall showed no ripples. For 30 years, during which at least 5,000,000 tons of asphalt have been ground to fine powder, no repairs have been necessary. One of the more notable applications was made by the Orleans Railway in their underground railway between the Place Denfert-Rochereau and the Port Royal, where the line passed by the Paris Observatory. Admiral Mouchez, who was then Chief of the Observatory, feared that his mercury bath for daylight observations would be shaken, and a foundation consisting of 633 cubic yards of bituminous concrete was therefore laid under the rails in 1894. The trains have run over it ever since, and no repairs have been found necessary. In the premises of the famous firm of Moët and Chandon, who keep a stock of 8,000,000 bottles of champagne in the cellars, it was feared that the machinery laid down for the electric lighting of their 8 miles of cellaring, would shake the wine, and in 1888 the Author put down 21 cubic yards of bituminous concrete, with a most satisfactory result. In 1892, the machinery being increased, the Author laid down an additional 17 cubic yards. In the Author's opinion, the vibration on the Central London Railway would be absolutely arrested by laying the rails on a foundation of bituminous concrete. Of course, the train service would have to be stopped, but a great deal might be done in the night at bad places.

For iron bridges over which, or under which, trains pass, this material is invaluable. Where a Portland-cement concrete will crack like mosaic, this material will stand. The Author has proved this in many cases, notably at an iron tubular bridge over the Seine at Elbeuf; at the Pont de l'Aqueduc, in Paris; and at the railway bridge over the Ceinture, or Girdle Railway, at Courcelles. At many forts round the French coast the very heavy pivot-guns are mounted on foundations of bituminous concrete, which absorbs the vibration produced by a heavy discharge. The Author has also used a coating of asphalt mastic in the granite embrasures of forts to counteract the splintering caused by the impact of small shells.

During the Commune of Paris, in 1871, the works of the Author's Company at the Quai de Valmy were under fire, and bullets which struck a heap of asphalt powder were flattened out. This led to the coating of iron turrets with asphalt. The late General Boulanger, when Minister of War, arranged with the Author to build a block of 390 cubic yards of bituminous concrete at the Polygon of Bourges, to test the effect of melinite shell, similar blocks being made of Portland-cement concrete and hydraulic-lime concrete. The whole was surrounded by a wall of unmortared stones. Melinite shells, 4 feet 3 inches in length by 1 foot $1\frac{3}{4}$ inch in diameter, with chrome-steel points, were fired at these masses. The result was that the cement- and lime-concrete blocks were pulverized; the bituminous concrete was not pulverized, but was torn asunder.

The chief asphalt mine in Europe is the Seyssel mine, the largest in France. It stretches from Seyssel to Bellegarde in the synclinal basin of the Rhône, which flows through the Department Ain on the east, and the Haute Savoie on the west. It is 10 miles in length and a little more than 3 miles in width, and its superficial area is about 20 square miles.

The bitumen which binds the soft lime oolite in this mine to form asphalt must have impregnated the limestone in a state of vapour, as is proved by the smoky appearance in the unimpregnated rock at Seyssel. The occurrence of bitumen in Trinidad, Venezuela, Cuba, and Mexico, on the surface of the earth, in its viscous state, just as it can be extracted from asphalt rock, would therefore appear to be due to the bituminous vapours having, at some depth, met with some porous rock like sandstone, through which they filtered upwards.

In Europe, the country that has taken the lead in laying compressed asphalt undoubtedly is Germany. There is more compressed asphalt paving in Berlin than in England and France together, there being about $2\frac{1}{2}$ million square yards, all laid on Portland-cement concrete, 8 inches in thickness. These magnificent roadways are one of the features of Berlin, and give it an aspect of brightness and cleanliness unknown to other European towns. The Germans have studied asphalt synthetically, and have produced sundry imitations. An artificial asphalt, composed of limestone and bitumen, introduced by Professor Dietrich, of Berlin, was laid in König-strasse, Berlin, but was afterwards replaced; a mixture of Vorwohle asphalt and bitumen is used to a considerable extent. These mixtures are, perhaps, cheaper than natural asphalt, since, being made on the spot, the cost of railway carriage from the mines is eliminated; but they are inferior to natural asphalt, and with heavy traffic the surface has to be frequently repaired. German contractors have followed the English lead, and have bought mines in Chieti in the Abruzzi, in Italy, and in Venezuela.

In conclusion, the Author is of opinion that English municipalities can borrow money so cheaply that it is not worth while to forego the advantages of hygienic streets, in asphalt, liquid and compressed.