12th Five Year Plan Network Project (NWP)

"DEVELOPMENT AND APPLICATION OF TECHNOLOGIES FOR SUSTAINABLE TRANSPORTATION (SUSTRANS)"

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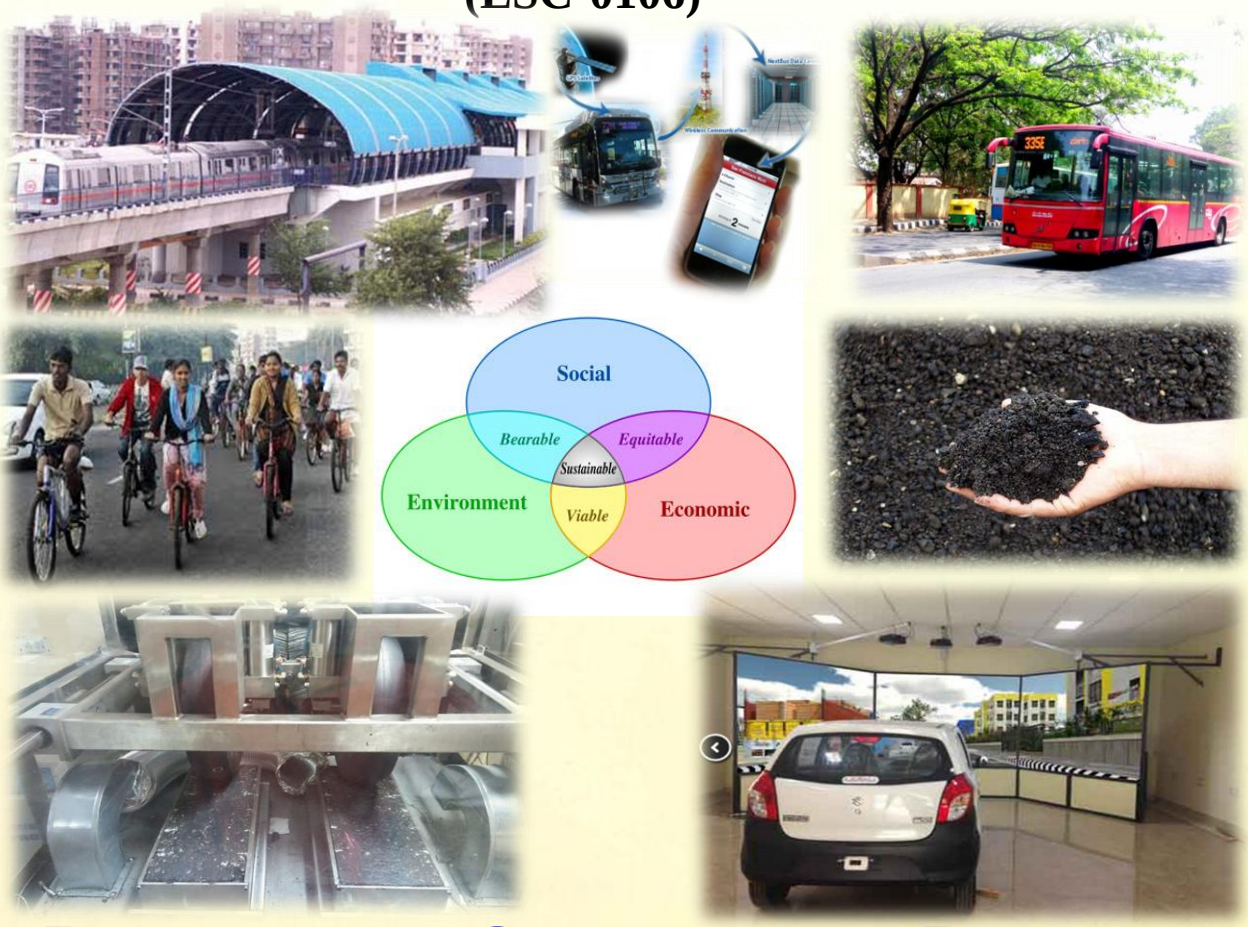

DESIGNS FOR SUSTAINABLE ROADS

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BACKGROUND

Sustainable development is a holistic practice that includes efforts to mitigate negative effects on every part of the road infrastructure and transportation system which are generally ignored in traditional transportation system planning. Sustainable transportation system must consider the interconnected issues under social, economy and environment areas. The need to plan for sustainable transport is evident since global warming possesses significant challenges for cities. The transport sector alone accounts for 24% of CO_2 emissions worldwide. The energy consumption is about 75 to 80% by road transport and by India's share is about 10% from all transport modes. Moreover, the sources of natural mineral aggregates are depleting fast due to massive infrastructure development and road construction activities going on in India which consumes huge quantity of material (about 15,000 tonnes of aggregates/km of highway). Also, enormous amount of energy is consumed in the production and transportation of huge quantities of Hot Mix Asphalt (HMA) required for road construction (about 90,000 litres of diesel/ km). Hence, there is an urgent need to develop technologies to utilize waste & marginal materials, innovative designs to achieve reduction in pavement thickness using high performance materials. Considering these issues, a research study on Development and Application of Technologies for Sustainable Transportation (SUSTRANS) has been taken up by this institute with the objectives of development of innovative technologies for utilization of waste and marginal materials in road construction, improved design methods and materials/ mixes towards achieving reduced pavement thickness, superior performing bituminous technology for long lasting pavements, warm mix technologies for road construction, use of reclaimed asphalt pavement (RAP) in construction and maintenance of roads and estimation of carbon footprints in road construction process. The research led to formulate the guidelines to design sustainable roads using waste, marginal materials and RAP and warm mix bituminous technologies, new design guidelines for reduced thickness of pavement and superior performing bituminous technology for long lasting pavements leading to conservation of depleting aggregate resources and huge savings in construction cost and energy. The summary of the research carried out is presented in the subsequent sections.

TECHNOLOGIES FOR UTILISATION OF WASTE AND MARGINAL MATERIAL IN ROAD CONSTRUCTION

Utilization of conventional natural aggregates in Road construction (NHDP, PMGSY, SARDP-NE, Programs of Govt. of India, State programs) has resulted in their depletion and tremendous increase in the total cost of construction. Review of National and International literature indicated the potential of different waste/ marginal materials for utilization in embankment and in different layers of road pavement. Also in Indian context, there is no database of these materials available in the country for the awareness of Implementing authorities and construction agencies.

Database of different waste materials viz. - Cinder, Coal ashes (pond ash, bottom ash and fly ash) from some of the power plants, Copper slag , Kimberlite, Jarofix, Steel slag, Jarofix, Jarosite, Zinc slag have been compiled on the GIS platform (Using Mapinfo software). The data mainly included typical Physical, Chemical and Geotechnical characteristics. Typical design cross-sections of their utilization in embankment and pavement have also been compiled, which would give idea to the users about their application in the field. The data would increase the confidence and awareness of the user agency like MoRTH, MoRD, NHAI, Local PWD's, Municipal Corporations etc. some of the wastes materials on which not

much R&D have been carried out (Foundry sand, Red mud, Soft aggregates) were also collected and investigated for their feasibility in Road construction.

Apart from utilization of different waste materials in embankment and pavement layers, different waste materials viz. Copper slag, Pond ash, Foundry and Yamuna sand were investigated for their utilization as a backfill material in the mechanically stabilized retaining wall. The results of the study clearly showed that these waste materials have a significant potential for use as structural fill materials in place of conventional materials for mechanically stabilized earth wall and Reinforced slope applications.

The feasibility of waste materials for utilization in both flexible and rigid pavement layers was also investigated. Cement stabilized fly ash and copper slag were studied for their feasibility in sub base and base layers of flexible road pavement, replacing the conventional aggregates. Different mechanistic parameters viz. Unconfined compressive Strength, Indirect tensile strength and fatigue characteristics of cement stabilized copper slag and fly ash waste materials were evaluated and studied to investigate their feasibility to replace the conventional Granular Sub base (GSB),Water Bound macadam (WBM) and Wet Mix macadam (WMM) layers in flexible pavement construction. The mechanistic characteristics of the cement stabilised fly ash determined in the laboratory were used to arrive at typical design pavement cross sections with its utility in sub base and base layers. It was also concluded that cement stabilized copper slag-fly ash mixes can also be effectively tried in base and sub base layers of road pavement.

Two types of waste materials viz. Foundry sand, Jarosite and a marginal soft aggregate were investigated for their feasibility for use in Pavement Quality Concrete (PQC) and Dry Lean Concrete (DLC) mixes in rigid pavement construction. It was concluded that, only about 20 to 30% foundry sand can be used as a replacement of fine aggregates in concrete mixes. Jarosite can be used in cement concrete, only in small amount of 10% by weight of cement in PQC mixes. Also, as the compressive strength achieved with soft aggregates, was only about 40% as compared to strength achieved with conventional aggregates, it was concluded that such aggregates cannot be used for rigid pavement construction.

CONVERSION OF CHROMIUM CONTAINING SOLID WASTE GENERATED IN LEATHER INDUSTRY INTO PAVEMENT MATERIALS

The methodology considered in the study include collection and characterization of chromium containing leather solid waste and conversion of solid waste generated from leather industry using pulse pyrolysis under controlled oxygen environment to produce chromium embedded carbon nanofibres. The chromium embedded carbon nanofibres was converted into road pavement materials through Solidification and Stabilization (S/S) using sand/ Portland cement and also bitumen. The materials were characterized by using detailed physical, chemical and rheological properties. Leachability studies were carried out. Semi-pilot scale studies were carried out to find the suitability of the modified bitumen for road applications and monitored the chromium III (Cr^{3+}) and chromium VI (Cr^{6+}) concentration. In the present study, the technology for the conversion of chromium containing micro - fined solid waste (MSPM) into carbonized micro - fined solid particulate matters (CMSPM) and its road application in bitumen modified with CMSPM was developed.

Concrete blocks were prepared by replacing cement and sand with different percentage of CMSPM. These blocks were manually checked for selecting the optimized percentage of

residue to screen the applicable blocks for road pavement application and the same composition was used for making standard block size (7cmx7cmx7cm) to test the compressive strength.

The CMSPM collected from the furnace after calcinations of CTBD was powdered and quantified. VG 30 grade bitumen (Vichoor bitu chemicals, Tamil Nadu) was used as a binder. Impregnations of CMSPM with bitumen were carried using both conventional melt blending technique and Microwave heating method.

The present study concluded that the chromium impregnated MSPM could be converted into carbon containing residue. The micro structure of the residue of pyrolysed chromium impregnated MSPM contains the nano fibrous carbon matrix. The nano fibrous matrix is expected to have high strength and hardness. The hardness due to the presence of nano fibrous carbon matrix would give desired wear resistance in the road applications. The modified bitumen was prepared with MSPM and bitumen in various compositions and semi-pilot scale studies was also carried by laying the road with different compositions and difference dimensions. The road withstands the movement of vehicle and also chromium leachability was nil.

IMPROVED MATERIALS, MIXES AND DESIGN METHODS TOWARDS ACHIEVING REDUCED PAVEMENT THICKNESS

Improved Material and Mixes

Though the present materials, mixes and design methods has adequate performance however with the increasing traffic and overloading of vehicles, the mechanical stability of the road surface is often being exceeded which leads to development of distresses. The sub-grade acts as the foundation of the pavement structure. The pavement structure should be such that sub grade is not over stressed. To take care of stresses and also the economy, the high quality material is provided at the top with reduction in quality as moving inside the pavement. The resilient modulus value of the top layer is high as compare to the lower layer so that it is able to distribute the wheel load stresses through a larger area per unit depth of the layer to keep them within permissible limits. This allows the pavement to sustain a large number of repeated load applications during the design life. This can be control by either providing thicker structure or using high quality material for different layers. The first approach requires resources for construction which are non-renewable. Therefore for sustainable design the alternate approach has to establish such as using stabilizers to improve the mechanistic properties of the present mixes or using some alternative or improved materials. There is need to study the improvement in the mechanistic properties of the mixes and establishing the alternative design.

Development of Highly Modified Hybrid Bitumen

Bitumen binder is a thermoplastic material which behaves as an elastic solid at low service temperatures or during rapid loading and viscous liquid at high temperatures or slow loading. It plays a significant role in creation of elastic properties of hot bituminous mixes and it is the essential binding constituent that determines visco-elastic behavior of bituminous mix and also influences the engineering and performance properties. This classical dichotomy creates a need to improve the performance of bitumen binders to minimize the load associated cracking that occurs at intermediate temperature and the plastic deformation at high temperatures.

Highly Modified Hybrid Bitumen (HMHB) was developed which can improve the performance of the bituminous mixes by providing the stiffness to mix at high temperatures and maintaining the elasticity at lower temperatures. HMHB is hybrid bitumen which works on interaction of base bitumen with different polymers. In laboratory, HMHB has shown better rheological properties in comparison to conventional grade of bitumen. Mixes prepared with HMHB has performed better, in laboratory, under various performance testing such as rutting, fatigue testing. The modulus of modified mixes is improved by which load taking capability of pavement can be increased. The endurance limit of mixes prepared with HMHB and VG 30 was also determined through laboratory testing. These limits can be adopted as indicative figures while designing flexible pavement

Stabilization/ modification of mixes used in lower layers

Changing physio-chemical properties of fine-grained soils by means of chemical stabilizers/modifiers is a more effective form of stabilization. The factors which affect the stabilization process include soil type, quantity of stabilizer, and degree of mixing, time of curing and dry density of the compacted mixture etc. Different chemical stabilization systems such as cement, additives based on organo-silane, additive based on alkali earth metals and synthetic zeolites was studied in laboratory to see effect on the engineering properties of the soil. On comparing the results obtained on soil stabilized with different stabilizer, it is difficult to suggest one type of system. Different system stabilized/modified the soil differently. The soil stabilized only with cement also has positive durability test. So, alone cement can also be used to stabilize the soil in comparison to other system in which along with cement other additives/modifier are also used.

TECHNOLOGY FOR SUPERIOR PERFORMING BITUMINOUS PAVEMENTS (SUPERBITPAVE)

Development of Different Grades of Bitumen

Roads in India are, in majority, flexible pavement type wherein the paved surfaces mostly have bituminous layers. The term bituminous materials is generally used to denote substances in which bitumen is present or from which it is derived. Bitumen, by definition is as an amorphous, black or dark-coloured, (solid, semi-solid, or viscous) cementitious substance, composed principally of high molecular weight hydrocarbons and is a visco-elastic material whose stiffness is temperature dependent.

Traditional grading of bitumen by viscosity and penetration are limited to just represent the binder to be used in the hot mix layered pavement. Presently, four viscosity grade (VG) binders have been recognised by BIS and include VG 10, VG 20, VG 30 and VG 40. Major Indian marketed Bitumen as per specifications conforming to IS: 73-include VG 10,VG 30 and of late VG 40.

Performance Grade Bitumen

Increased traffic loads and change in climatic condition led to the development of Superpave Performance Grade (PG) binder for a better performing and durable roads in USA. The relationship between binder properties and conditions of use are more complete and precise in Superpave PG system. However this concept is yet to be adopted in Indian applications. A Superpave Performance Grading mapping with commercially available bitumens is expected to streamline the usage for best performance of pavements. However, this needs a vigorous and rigorous exercise of characterising the various bitumens from different sources at different grades.

SUPERBITPAVE Concept

The Superpave Performance-Graded Binder Specification is based on providing a binder that is resistant to rutting, fatigue cracking, and low-temperature cracking at specific pavement temperatures. The binder temperature ranges in the specification are based on the high and low temperatures at which a binder reaches critical values of distress-predicting properties. Reliability factors included in the design method account for normal pavement temperature variations and allow the designer to make a rational decision regarding the range of temperature extremes for which to design. Binder grade is selected based on design high and low pavement temperatures expected at the construction site and on desired reliability. The most common method of selecting a binder grade is to determine the design air temperature range for the specific project and then to establish the corresponding design pavement temperatures. Before selecting the grade to be used, the designer must also consider traffic volume and traffic speed.

Technology for SUPERBITPAVE

In this study, it was envisaged to procure bitumen of different grades from various sources and evaluate for basic properties, the mix properties using these and then map on a Indian PG grade chart. Also, along with the available bitumen grades designated as VG 30 and VG 10, the commercially unavailable grades of VG 20, VG 40 and VG 50 were formulated to fit in the Superpave PG binder system. Further, the based on the rheological parameters of the binders, guidelines giving directions for obtaining tentative Indian PG grade have been made. Based on altitude and air temperature of different regions of India, expected pavement temperatures were estimated, which were employed as indicators for the appropriate binder selection for the improved performance of the bituminous pavements. Bituminous mix designs were made with Marshall and Superpave methods and the performance under wheel loading were evaluated using 'Large Scale Wheel Track Tester'.

DEVELOPMENT OF HALF WARM MIX TECHNOLOGIES FOR ROAD CONSTRUCTION

Hot mixed bituminous materials are widely used for construction and maintenance of flexible pavements. The hot mix technology contributes greenhouse gases and consume high energy. The manufacturing process for these mixes consumes high energy for heating of aggregate as well as bitumen during production of bituminous mixes. This eventually contributes to global warming, which has now become a serious concern and focus of research. Therefore, road construction sector has been looking for sustainable construction technologies to produce bituminous mixtures at comparatively lower temperature to address (i) decrease in emissions of CO_2, (ii) reduced energy requirement for heating of aggregates and bitumen and (iii) least contribution to global warming.

The development of Warm Mix Asphalt and Half Warm Mix Asphalt technologies have a potential of revolutionizing the production and laying of bituminous mixes at lower temperatures. Besides the conventional cold and hot bituminous mixes, there are various energy efficient mixes and construction technologies. Emulsion based half warm mix asphalt (HWMA) is one of them. The product and process has been developed by CRRI using cationic bitumen emulsion without adding chemical additives. The use of bitumen emulsion further reduces the mixing temperature by about 80^{o} C in case of half warm mixes and by 30-35^{o}C in case of warm mix as against hot bit mixes using additives in bitumen. The Performance of HWMA is evaluated in the laboratory and validated through semi-field and field trials.

USE OF RECLAIMED ASPHALT PAVEMENT (RAP) IN CONSTRUCTION AND MAINTENANCE OF BITUMINOUS ROADS

A good road network is a vital infrastructure requirement for economic growth of the country. There is huge road asset in the country but it is still inadequate to meet the accessibility and mobility requirements. Several ambitions road development programmes such as National Highway Development Programme, Pradhan Mantri Gram Sadak Yojna (PMGSY), Special Accelerated Road Development Programme in the North-Eastern region (SARDP-NE) are in progress. For these, huge materials and energy inputs are required.

The conventional method of providing bituminous surfacing on flexible pavements requires significant amount of fuel and materials. Therefore, in order to reduce consumption of fuel and aggregates in bituminous road construction, pavement recycling technology is adopted in countries abroad. Recycling of existing bituminous pavement to produce new pavement led to considerable savings of material, expenditure, and energy. HMA (Hot Mix Asphalt), WMA (Warm Mix Asphalt) and CMA (Col Mix Asphalt) are the available technologies, where RAP can be used for saving of aggregates.

The use of RAP in road construction is the need of the day as it can save considerable pavement materials especially mineral aggregates. In this study, use of RAP and its different dosage in hot mix, and cold mix are investigated. The study included characterization of RAP, design of mixes, study of performance properties in laboratory and semi field studies by Large size wheel tracking system (LSWT).

From the laboratory and semi field study, it indicates that addition of RAP improves the properties of the bituminous mixes. The only drawback is that the final performance of the RAP containing mix depends on the properties of ingredients in RAP and its optimization. So, proper characterization of RAP material is very much essential before going for mix design. Results also show that 100% natural aggregate can be replaced by recycled material in cold recycle technology (Foamed and Emulsion recycled technology). RAP is still regarded as black rocks when they are used in cold recycling. Knowledge about the interaction between virgin binders and aged residual binders in cold recycled mixes is still ambiguous and needs further exploration. Hence, there is a need for large scale field trial to be carried out for better understanding of the performance of cold mixes.

CARBON FOOTPRINTS IN ROAD CONSTRUCTION PROCESS

Carbon foot print is a term used to describe the total amount of carbon dioxide and other green house gas (GHG) emissions for which an individual/ process/ organization/ activity is responsible. The challenge of global climate change has motivated state transportation agencies involved in the construction and maintenance of transportation infrastructure to investigate strategies that reduce the life cycle greenhouse gas (GHG) emissions associated with the construction and rehabilitation of highway infrastructure. The road sector is coming under pressure to review current practice and the potential to reduce carbon emissions.

In the direction of reducing GHG emission, different approaches are adopted for road construction and maintenance such as Warm Mix and Cold Mix Technologies. Warm mix asphalt is produced at temperatures 20 to 40ºC lower than hot mix asphalt (HMA). Cold Mix Asphalt is produced and paved at ambient temperature using bitumen emulsion. The immediate benefit of producing and placing asphalt mixes at a lower temperature is the

reduction in energy consumption, greenhouse gas emissions, fumes, and odours generated at the plant and the paving site. The life cycle approach has been accepted as a robust method of measuring carbon footprint.

In the present study, the common methodology of road carbon footprint, application of results in sustainable construction assessment schemes and resources available to undertake such analysis are outlined. Various types of projects (covering a broad scope from bituminous to rigid pavement) have been considered as case studies to understand the contributions to GHG emissions to environment from road construction activities.

Followings are some emerged conclusions:

- The embodied energy of material and plays a vital part for emission for bituminous road (which includes heating of bitumen and aggregate) construction. Construction machinery has negligible effect on the total emission.
- In total, emission from construction of rigid pavement is huge compared to flexible pavement. If emission only during the construction (equipment) is considered without considering the embodied emission of materials like cement and steel bar, then rigid pavement has lower emission during construction process.
- First stage of projects calculates quantities of items of road works, based on general characteristics of the project. The output of this stage is a "bill of quantities" at feasibility study stage and the work items are broken down into "work series" reflecting the types of works. Second stage calculates the quantities of generators of GHG emissions based on the quantities of items of road works and on general characteristics of the project. These generators have been broken down into materials, transport, equipment and others.
- Models for GHG emission are developed which estimates GHG Emission from Road construction using cold mix technology, warm mix technology and hot mix technology through onsite case studies.

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