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To Study the Freeze-Thaw Resistance of Crumb Rubber Modified Bituminous Mix Using Ground Granulated Blast Furnace Slag (GGBFS) as Filler

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ABSTRACT- First Asphalt concrete consists of Aggregates, filler and Bitumen. Generally in practice, cement, limestone and stone dust filler materials are used in Asphalt pavement construction work. The recycled rubber produced from automotive and truck tires called crumb rubber is also being used in bituminous pavement construction. Ground granulated blast furnace slag (GGBFS) is a by-product of iron/steel industry which can also be used as a filler material in Asphalt concrete. In the present study an attempt is made to asses and evaluate the effects of repeated freezing and thawing on Crumb Rubber Modified Bitumen (CRMB) using (GGBFS) as a filler material and compare the test results with the samples using OPC as filler by carrying out experimental investigation such as Marshall mix design test to evaluate stability, flow and void characteristics of samples. The Asphalt concrete samples were made using Bituminous concrete (Grade II) with bitumen content fixed at 5.4% From Marshall mix design and crumb rubber content fixed at 15% by weight of the binder based on literature survey. The amount of (GGBFS) used as filler material is fixed at 4% on the basis of literature survey. Moreover the focus has been on exploring options to enhance the condition of pavements and save subsequent maintenance and frequent overlaying expenses in cold regions where the asphalt pavements undergo deterioration due to seasonal freezing-thawing.

KEYWORDS- Asphalt, Bitumen, Bituminous concrete, CRMB, Filler, GGBFS.

I. INTRODUCTION

The evolution and advancement in transportation facilities have been closely linked with the development of human being throughout the history of the world[1]. Transportation contributes to the economic, industrial, social and cultural development of any country. Insufficient transportation facilities retard the process of socio-economic and cultural development of the country[2]. Development of adequate transportation system in a country indicates its economic growth and progress in social development.

Transportation by road system is the only mode which could give maximum flexibility of service from origin to destination, to one and all [3]. Various classes of vehicles such as cars, buses, trucks, two-wheelers, etc. may be permitted to make use of the roads. Apart from the road vehicles, pedestrians also make use of the road system. Road transportation has the maximum flexibility for travel with reference to the choice of the route, direction, time and speed of travel[4]. Road transportation system is the only mode which provides the movement of passengers and goods individually from the place of source up to the destination of any trip along the land[5]. The other transportation modes, like railways, waterways and airways have to depend on transportation by road for the service to and from their respective terminuses, i.e., railway stations, harbors and airports[6]. Therefore the road network is essential to serve as a feeder system for all other modes of transportation and also to supplement them. Therefore it is necessary to develop a well-planned road network throughout the country so as to serve both as an independent transport system and also as a feeder transport system for the other three modes of transportation[7].

The development of the road network leads to the growth of the automobile industry which leads to the increasing manufacturing of automobiles[8]. Thus increase in manufacturing of automobiles also leads to the increase of waste tyres. The disposal of waste tyres is a serious problem that leads to environmental pollution. Earlier the waste tyres were disposed of in sanitary landfills or burned in the open[9]. Nowadays these practices of disposing waste tyres in sanitary landfills and burning them outdoors is becoming unacceptable because of depletion of available sanitary landfill and environmental concerns. Studies have shown that the crumb rubber obtained from shredding of scrap tyres from automobiles enhances the properties of bitumen leading to excellent pavement life, driving comfort and low maintenance of pavement [10]. Bitumen used for road construction in India is estimated to be 5 million tons per year. An average of 750,000 tons of crumb rubber can be put to use annually if used as a modifier in bitumen for pavements[11]. The use of crumb rubber waste obtained from discarded tyres of automobiles in hot bituminous mixes improves pavement performance, protects the environment and provides low cost and greener roads. Majority road network in India comprises flexible pavement in which Hot Mix Asphalt (HMA) is used in the bituminous layer.

Ground granulated blast furnace slag (GGBFS) is a by-product of iron in blast-furnace. It mainly consists of silicate and aluminosilicate of melted calcium that periodically needs to be removed from the blast-furnace. Similar to fly ash, the chemical compositions of (GGBFS) depend on the raw materials used in the production of iron while the physical properties depend on the cooling process used to cool down the molten materials [12]. The cooling process consists of rapidly cooling down the molten material by either quenching in water with high pressure water jet to form amorphous glassy granulated particles or by the pelletization process, a combination of water jet and air, to produce spherical glassy pellets of various sizes. Small particles are then ground to < 45 μm with a surface area varying between 400 and 600 m2/kg. (GGBFS) is a hydraulic material which can hydrate in the presence of water to produce a hardened compound. Several factors including chemical composition and glass content affect the reactivity index of (GGBFS) that contributes to its cementitious performance [13].

Flexible pavements in cold regions experience severe seasonal climatic conditions in a year. Freeze-thaw cycles and frost action is a major cause of pavement deterioration in Kashmir and other cold regions of India [14]. The extreme variations in temperatures have significant influences on the performance of pavement. Previous research demonstrated that the variations of temperature can create tensile stress at the bottom of the asphalt base layer even more than traffic loads [15]. These significant temperature variations in combination with the moisture inside the pores, traffic loads, and loss of bearing capacity due to saturated underlying granular layers during the spring season can result in the growth of premature deterioration and fatigue cracking. Analysis of the daily variation of temperatures and its effect on the performance of asphalt pavements in Kashmir needs to be examined at a more precise assessment [16]. A freeze-thaw cycle is considered when the temperature falls below 0ºC or -1ºC and returns above 0ºC or even 1ºC.

Effect of Freeze-thaw Cycles on Asphalt Mixtures Freeze-thaw cycles can create damage which is related to temperature and moisture susceptibility that significantly affects the performance and durability of flexible pavements in cold regions[17]. Freeze-thaw damage on asphalt mix is a major cause of degradation of pavements in cold regions [18]. The degradation process of an asphalt mix in terms of freeze-thaw cycles is categorized as decreased in strength, performance loss, and adhesion loss between the aggregate and binder.

Here the main focus is to find different additive components to improve the mix rather than spending tons of money over maintenance work.

II. LITERATURE REVIEW

Presently in India bitumen modified with various types of modifier such as crumb rubber, natural rubber, reclaimed polyethylene and polymers are being used for construction of bituminous roads. Numerous products are also available in the market which are used as bitumen modifiers. Readily blended type of Polymer modified bitumen, crumb rubber modified bitumen (CRMB) and natural rubber modified bitumen are also available in the market commercially. As per IRC: SP: 53-2010 these products must be evaluated for their appropriateness in an approved laboratory by conducting various tests to know their properties.

The abundance and increasing quantity of waste tyres of vehicles and their disposal is a serious problem that leads to environmental pollution [19]. The longstanding practice of disposing waste tyres of vehicles in sanitary landfills or burning them openly is becoming objectionable in the present scenario because of exhaustion of available sanitary landfill sites and environmental concerns respectively. Studies have shown that the crumb rubber obtained from shredding of scrap tyres from automobiles improves the properties of bitumen leading to excellent pavement life, driving comfort and low maintenance of pavement. Bitumen used for road construction in India is estimated to be 5 million tons per year. An average of 750,000 tons of crumb rubber can be put to use annually if used as a modifier in bitumen for pavements. The use of crumb rubber waste obtained from discarded tyres of automobiles in hot bituminous mixes improves pavement performance, protects the environment and provides low cost and greener roads [20]. Majority road network in India comprises flexible pavement in which Hot Mix Asphalt (HMA) is used in the bituminous layer.

III. OBJECTIVE OF THE STUDY

- To study the effects of 2, 4, 6, and 8 freeze-thaw cycles on the performance of CRMB modified bitumen using (GGBFS) as filler material.
- To determine the Marshall Stability, Marshall Flow, specific gravity and void characteristics of crumb rubber modified bitumen using (GGBFS) as filler, samples at varying freeze-thaw cycles.
- Recommended optimum quantity of (GGBFS) filler suitable for a region experiencing sub-zero temperatures based on the experimental study.
- To compare the compatibility of using (GGBFS) as a replacement of ordinary Portland cement as a filler.

IV. METHODOLOGY

Various materials were procured in order to perform this study such as aggregates, bitumen binder, fillers, crumb rubber, ground granulated blast furnace slag (GGBFS) etc. and the standard tests were performed on each. The coarse aggregate used in this study were collected from a local stone crusher from (Athwajan). Fine aggregates were collected from the crusher with fractions retained on 0.075 mm IS sieve and passing 4.75 mm IS sieve. Ordinary Portland Cement (OPC) and Ground granulated Blast Furnace Slag (GGBFS) has been used as filler and paving grade bitumen (VG-10) has been used as the binder. The bitumen modifier used in this study is crumb rubber conforming to mesh size 80 and the amount of crumb rubber was taken as 15% by weight of bitumen (optimum) based on a literature survey to make hot mix asphalt mix. (Tefera et al. 2018). Standard tests are performed on aggregate like gradation, crushing test, Los Angeles abrasion test, aggregate impact test, soundness test, shape test, specific gravity and water absorption test as well as stripping value tests were conducted as per IS:2386 and IS:6241. Aggregate grading in compliance to B.C (grade-II) as per the (MORT&H) specifications were used for the present study. The bitumen used in this study conforms to grade (VG-10). Wet mixing method was used in this study for mixing of crumb rubber with bitumen. In this method thorough mixing of the crumb rubber in hot bitumen is done by holding the blend of crumb rubber and bitumen at around 180C for a designated least period of time (typically 30 minutes) to allow an interaction between the crumb rubber and bitumen. The bituminous mix was designed by using the Marshall Method of mix design. The Marshall test was used in this study to obtain the optimum bitumen content based on ASTM D-1559-96. In this particular case the optimum bitumen content used is (5.4%) according to a literature survey. Fig. 1 shows Methodology chart.

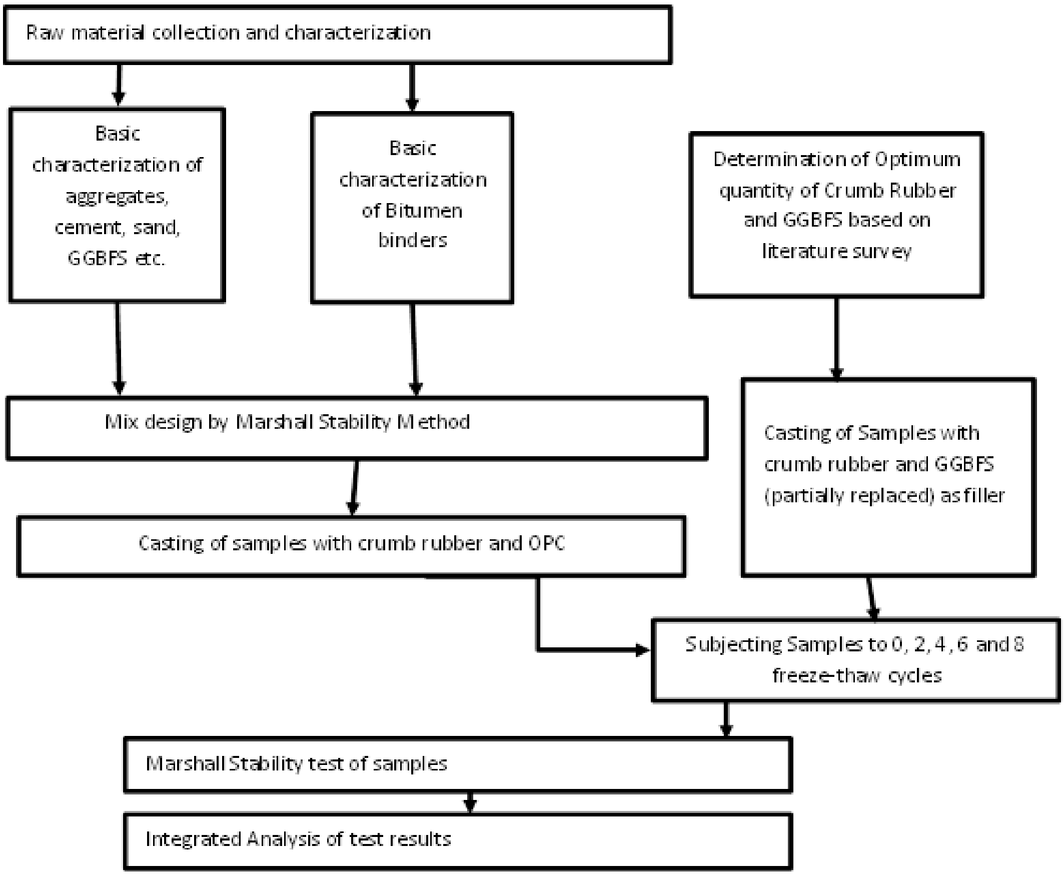

Figure 1: Methodology chart

A. *Preparation of Test Samples*

- The coarse aggregate, fine aggregate and filler are proportioned as per dry mix design, such that the compacted specimen should have a thickness of about 63.5 cm, which approximately equals to 1200 grams Figure 2 shows Samples put in freezer for freezing and Figure 3 shows Samples taken out of freezer
- Aggregate and filler materials are heated in temperatures of 150-170 degrees. Also the mould and rammer are heated for temperature above 100 degrees
- Thorough mixing of the crumb rubber in hot bitumen is done by holding the resulting blend of crumb and bitumen at around 180oC for a minimum period of time (typically 30 minutes) to allow an interaction between the crumb rubber and bitumen.
- Then the required percentage of bitumen is mixed properly with aggregates.
- The mix is placed in the Marshall mould having standard size 10.16 cm diameter and 6.35 cm height.
- Mix is compacted by rammer having weight of 4.54 kg and rammed by giving 25 blows on each side.
- If the compacted specimen has height other than 63.5 cm then necessary corrections are applied.
- After that the sample is extracted from the mould by a sample extractor after curing.
- The samples were prepared with varying quantities of ordinary Portland cement (OPC) replaced by ground granulated blast furnace slag (GGBFS) @ 0%, 10%, 20%, 30%, 40% and 50%, and the process of freezing and thawing was carried out.

B. *The processes of Freeze-thaw were Designed and Performed as follows*

- The samples were divided into numerous groups. One of the groups of samples was placed at room temperature and other groups of samples were immersed into a water bath for half an hour.
- Each sample was taken out of the tank and placed into a plastic bag with 12 ml of water. The bag was put in refrigerator for 16 hours at (−20°C) until all the water in plastic bag was frozen.
- The samples were removed from plastic bags and placed into a water bath for 8 hours with constant temperature 60°C until thawing process was completed.
- After steps 1, 2, and 3, one Freeze-Thaw cycle was completed. In this study, the number of Freeze-Thaw cycles performed was 2, 4, 6 and 8 for Marshall Stability and void analysis to be tested at each freeze-thaw cycle.

- After completing the freezing and thawing process of the samples, the Marshall Stability and void analysis is carried out.

Figure 2: Samples put in freezer for freezing

Figure 3: Samples taken out of freezer.

V. RESULTS AND DISCUSSIONS

- Table 1 shows the Marshall Stability (KN) test results for different quantities of (GGBFS) filler material for all Freeze-thaw cycles:

Table 1: Marshall Stability test results (KN)

Freeze-thaw cycles	**CRMB mix with (OPC) as filler**	**CRMB mix with filler replaced by 10% (GGBFS)**	**CRMB mix with filler replaced by 20% (GGBFS)**	**CRMB mix with filler replaced by 30% (GGBFS)**	**CRMB mix with filler replaced by 40% (GGBFS)**	**CRMB mix with filler replaced by 50% (GGBFS)**
0	**12.17**	**12.17**	**12.17**	**12.16**	**12.17**	**12.2**
2	**9.44**	**9.45**	**9.44**	**9.42**	**9.44**	**9.45**
4	**8.02**	**8.02**	**8.03**	**8.03**	**8.03**	**8.05**
6	**6.15**	**6.14**	**6.15**	**6.16**	**6.16**	**6.16**
8	**5.55**	**5.56**	**5.56**	**5.55**	**5.56**	**5.6**

- Figure 4 depicts the variation of Marshall Stability with freeze-thaw cycles

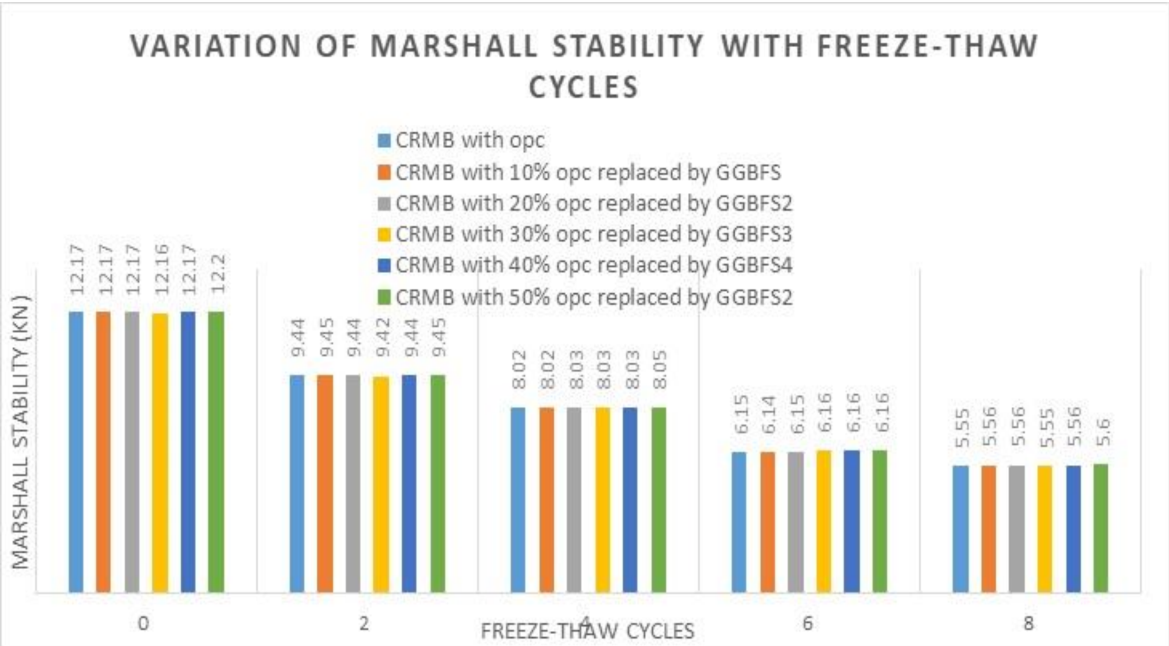

Figure 4: Variation of Marshall Stability with freeze-thaw cycles

- Table 2 shows Marshall Flow test results for different quantities of (GGBFS) filler material for all Freeze-thaw cycles:

Table 2: Marshall Flow test results

Freeze-thaw cycles	CRMB mix with (OPC) as filler	CRMB mix with filler replaced by 10% (GGBFS)	CRMB mix with filler replaced by 20% (GGBFS)	CRMB mix with filler replaced by 30% (GGBFS)	CRMB mix with filler replaced by 40% (GGBFS)	CRMB mix with filler replaced by 50% (GGBFS)
0	**5.44**	**5.44**	**5.42**	**5.42**	**5.4**	**5.38**
2	**4.52**	**4.52**	**5.42**	**5.41**	**5.41**	**5.35**
4	**4.57**	**4.55**	**5.4**	**5.41**	**5.41**	**5.33**
6	**4.48**	**4.48**	**5.41**	**5.38**	**5.38**	**5.3**
8	**4.45**	**4.43**	**5.39**	**5.37**	**5.38**	**5.26**

- Figure 5 shows the Variation of Marshall Flow with Freeze-Thaw cycles.

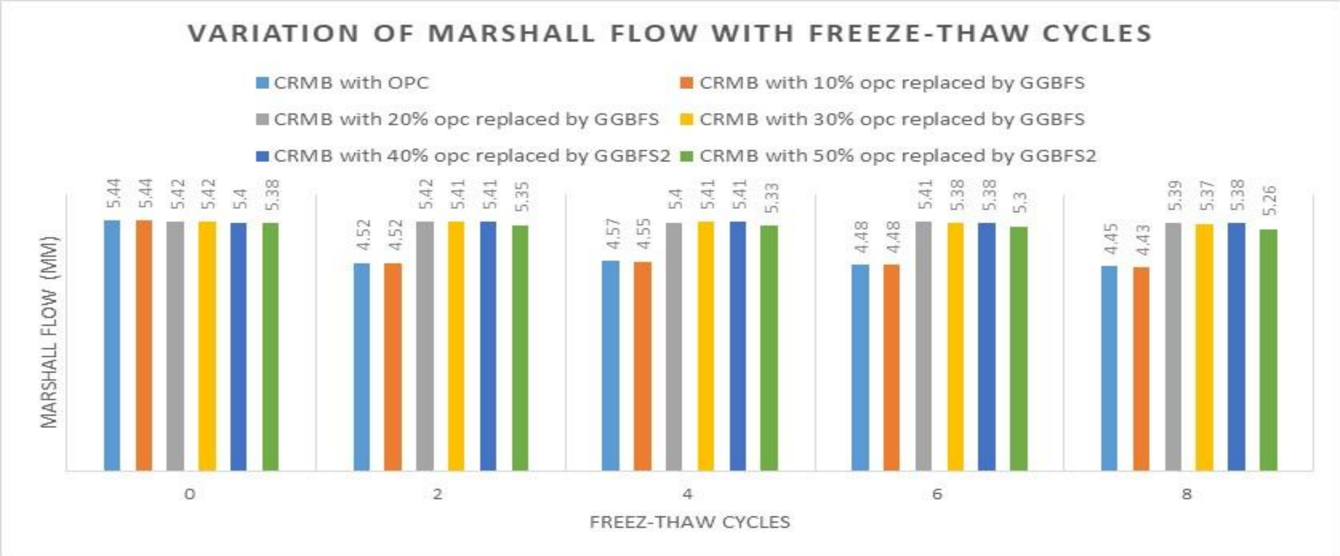

Figure 5: Variation of Marshall Flow with Freeze-Thaw cycles Void characteristics for all Freeze-Thaw cycles

- Table 3 shows Crumb rubber modified bituminous mix with ordinary Portland cement (OPC) as filler material:

Table 3: Void characteristics for all Freeze-Thaw cycles with OPC as filler

Freeze-thaw cycle	Weight in air (gm)	Weight in water (gm)	G_m (gm/cc)	Va (%)	Vb (%)	VMA (%)	VFB (%)
0	**1182**	**705**	**2.45**	**7.28**	**12.75**	**18.24**	**60.36**
2	**1181**	**703**	**2.45**	**7.18**	**12.74**	**19.92**	**63.95**
4	**1181**	**706**	**2.45**	**7.11**	**12.74**	**19.85**	**64.18**
6	**1182**	**710.5**	**2.45**	**7.23**	**12.72**	**19.95**	**63.75**
8	**1179**	**701.5**	**2.44**	**7.46**	**12.68**	**20.14**	**62.95**

- Table 4 shows the Crumb rubber modified bituminous mix with ordinary Portland cement (OPC) as filler material replaced by 10% of ground granulated blast furnace slag (GGBFS) by weight:

Table 4: Void characteristics for all Freeze-Thaw cycles with OPC replaced by 10% of (GGBFS) by weight

Freeze-thaw cycle	Weight in air (gm)	Weight in water (gm)	G_{m} (gm/cc)	Va (%)	Vb (%)	VMA (%)	VFB (%)
0	1183	704	2.45	7.44	12.72	20.16	63.09
2	1182	704.5	2.45	7.3	12.72	20.02	63.56
4	1184	705	2.46	6.85	12.77	19.62	65.08
6	1182	707	2.47	6.4	12.82	19.22	66.7
8	1185	705	2.46	6.71	12.77	19.48	65.55

- Table5 shows Crumb rubber modified bituminous mix with ordinary Portland cement (OPC) as filler material replaced by 20% of ground granulated blast furnace slag (GGBFS) by weight:

Table 5: Void characteristics for all Freeze-Thaw cycles with OPC replaced by 20% of (GGBFS) by weight

Freeze-thaw cycle	Weight in air (gm)	Weight in water (gm)	G_{m} (gm/cc)	Va (%)	Vb (%)	VMA (%)	VFB (%)
0	1184.5	705	2.46	6.92	12.77	19.69	64.85
2	1184	705.5	2.46	6.99	12.77	19.76	64.62
4	1181	704.5	2.45	7.23	12.72	19.95	63.75
6	1182	703.5	2.45	7.12	12.72	19.84	64.11
8	1185	702	2.44	7.54	12.66	20.2	62.67

- Table 6 shows Crumb rubber modified bituminous mix with ordinary Portland cement (OPC) as filler material replaced by 30% of ground granulated blast furnace slag (GGBFS) by weight:

Table 6: Void characteristics for all Freeze-Thaw cycles with OPC replaced by 30% of (GGBFS) by weight

Freeze-thaw cycle	Weight in air (gm)	Weight in water (gm)	G_{m} (gm/cc)	Va (%)	Vb (%)	VMA (%)	VFB (%)
0	1182.5	704	2.45	7.44	12.72	20.16	63.09
2	1182.5	706	2.47	6.58	12.82	19.4	66.08
4	1181	707	2.47	6.51	12.82	19.33	66.32
6	1182.5	704	2.45	7.09	12.72	19.81	64.2
8	1183	704	2.44	7.54	12.66	20.2	62.67

- Table7 shows Crumb rubber modified bituminous mix with ordinary Portland cement (OPC) as filler material replaced by 40% of ground granulated blast furnace slag (GGBFS) by weight:

Table 7: Void characteristics for all Freeze-Thaw cycles with OPC replaced by 40% of (GGBFS) by weight

Freeze-thaw cycle	Weight in air (gm)	Weight in water (gm)	G_{m} (gm/cc)	Va (%)	Vb (%)	VMA (%)	VFB (%)
0	1182.5	707	2.47	6.61	12.82	19.43	65.98
2	1182	705	2.46	6.92	12.77	19.69	64.85
4	1181.5	704	2.46	7.23	12.77	20	63.85
6	1182.5	704.5	2.45	7.16	12.72	19.88	63.98
8	1182	705	2.45	7.09	12.72	19.81	64.2

- Table 8 shows Crumb rubber modified bituminous mix with ordinary Portland cement (OPC) as filler material replaced by 50% of ground granulated blast furnace slag (GGBFS) by weight:

Table 8: Void characteristics for all Freeze-Thaw cycles with OPC replaced by 50% (GGBFS) by weight

Freeze-thaw cycle	Weight in air (gm)	Weight in water (gm)	$G_{m\ (gm/cc)}$	Va (%)	Vb (%)	VMA (%)	VFB (%)
0	1182	706	2.45	7.3	12.72	20.02	63.54
2	1181	706.5	2.48	6.16	12.87	19.03	67.63
4	1181.5	707	2.47	6.47	12.82	19.29	66.45
6	1182	704	2.46	6.67	12.77	19.44	65.68
8	1181	705	2.45	6.95	12.77	19.72	64.75

- Figure 6 depicts the variation of air voids with freeze-thaw cycles

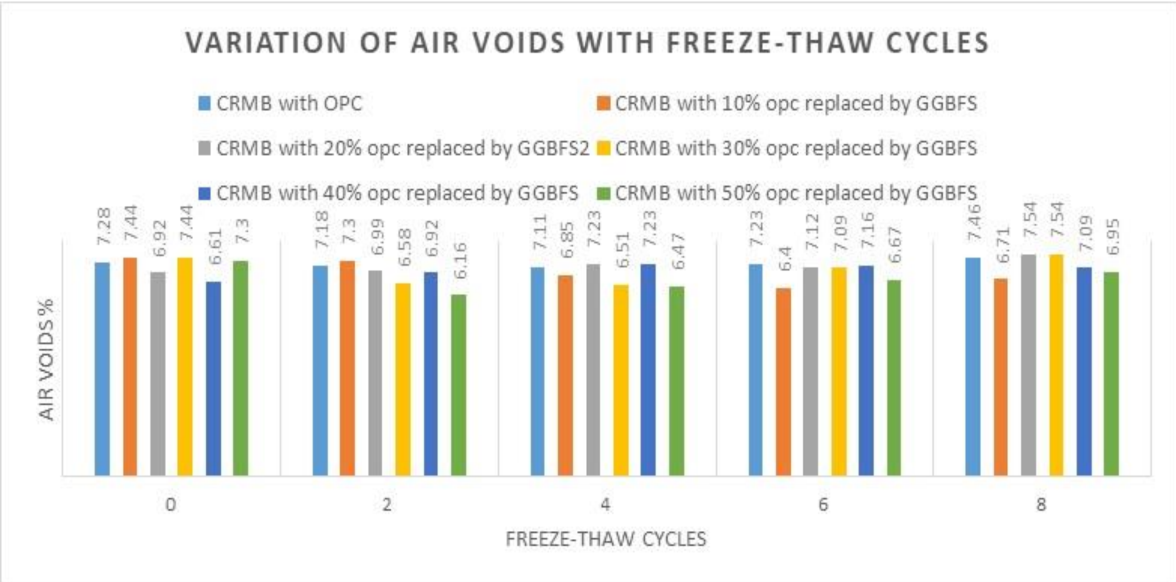

Figure 6: variation of air voids with freeze-thaw cycles

- Figure 7 shows Variation of unit weight with freeze-thaw cycles

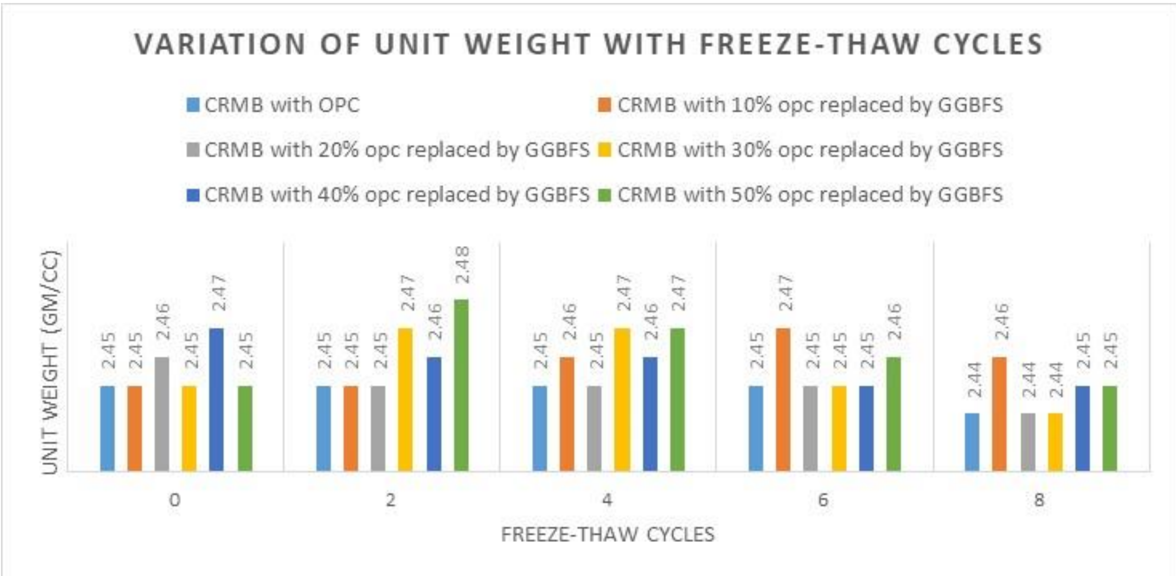

Figure 7: Variation of unit weight with freeze-thaw cycles

- Figure 8 shows the variation of VMA (%) with freeze-thaw cycles

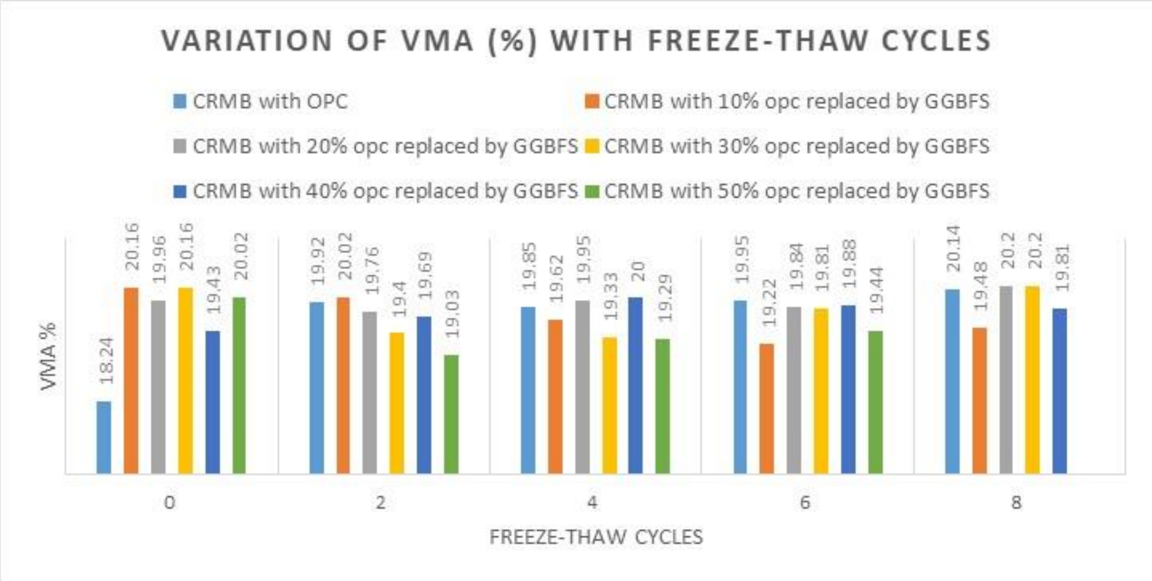

Figure 8: variation of VMA (%) with freeze-thaw cycles

- Figure 9 shows the variation of VFB (%) with freeze-thaw cycles

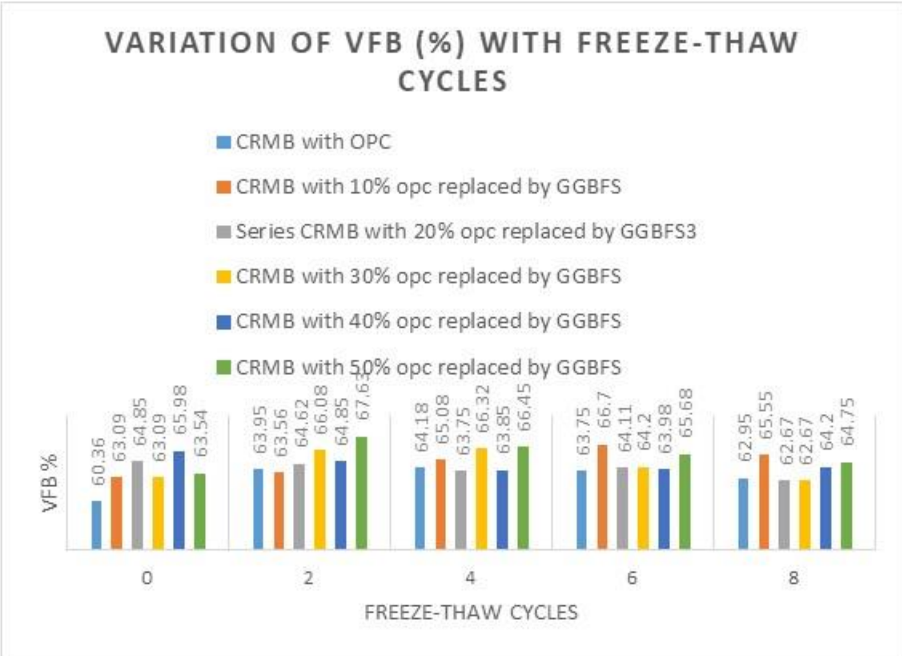

Figure 9: variation of VFB (%) with freeze-thaw cycles

VI. CONCLUSION AND FUTURE SCOPE

In this study various tests were conducted on the CRMB HMA mix to evaluate the effect of repeated freezing and thawing on the properties of the bituminous mixes. Based on these test results, the following conclusions were made:

- After 0, 2, 4, 6, and 8 Freeze-Thaw cycles, the stability of the samples with 10%, 20%, 30%, 40% and 50% (GGBFS) as filler showed least deviation from the stability of samples containing 100% OPC as a filler material.
- The Marshall Flow values increased after adding 20% GGBFS, however the values of flow remained almost in the same range beyond 20% addition of (GGBFS) as a replacement of OPC.
- The samples with 50% OPC replaced with GGBFS showed least air voids after 2 freeze-thaw cycles.
- After 2 freeze-thaw cycles the samples with 50% GGBFS showed higher density
- After 4 freeze-thaw cycles the samples with 30% and 50% GGBFS showed higher density
- After 6 freeze-thaw cycles the samples with 10% and 50% GGBFS showed higher density
- After 8 freeze-thaw cycles the samples with 10%, 40% and 50% showed higher density.

- Therefore it can be concluded that the samples with 50% GGBFS showed higher density.

On the basis of test results found in the above study it is concluded that the material called ground granulated blast furnace slag (GGBFS) can be effectively used as a replacement of ordinary Portland cement (OPC) up to the range of about 50% as it showed satisfactorily least deviation of test results from the samples containing only OPC as a filler material. As GGBFS costs less than OPC therefore using GGBFS can reduce the cost of the construction and well management and disposal of GGBFS which is an industrial waste product.

In the future course of research, the mixes can be evaluated for indirect tensile stress test, tensile strength ratio and the freeze-thaw effects on rutting resistance, skid resistance and fatigue performance of various mixes with different quantities of GGBFS can be studied.

Further, based on laboratory results the mix can be implemented in field conditions and observations can be made on the overall behavior of mixes.

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