Feasibility Study of Modified Patching Premix Design Using Response Surface Methodology (RSM)

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Abstract
Road patching is a short-term solution used to repair road surface fractures and to ensure the efficiency of transport functions and road user safety. The patching also prevents the road subgrade from worsening if the failure is repaired immediately. The continued surface failure caused on the road is due to high traffic loads and poor-quality construction. If the surface failure is not restored immediately, it could increase the risk to the safety of road users at a hazardous stage, mainly motorcyclists. This study uses a design thinking method to solve the problem and gain the idea. An exploratory empathy process is carried out randomly on the selected road samples. The maintenance practical procedure information carried out by local municipalities or private agencies is also studied to support the literature from previous research. The article will apply primary data as the initial review study. Furthermore, the Response Surface Methodology (RSM) application is identified to get a design model to simplify the design ratio. The result showed that the cubic model was the most equivalent and optimum with the squared R-value of 0.9886. It shows that the correlation of the selected variables is appropriate.

Keywords*:* Pothole failure, Patch, Asphalt/Bitumen

1.0 Introduction

A road surface-wearing course with a life span of 10-15 years without any maintenance is considered effective pavement. Even so, across time, it will experience a degree of deterioration according to the duration of its cycle. A slump or decay of the roadway exists if the road can no longer be used safely and does not reach the objectives of its initial function. The study identifies several factors of pavement failure; the road surface becomes broken or too slippery, and the road requires too much budgeting in the early stages as soon as the pavement has been completed. Road maintenance is essential to ensuring the highway's quality is always in good condition. The results of the perception study of the quality of the implementation of the fellowship road by Haryati Shafii et al. (2017) identified the factors causing the failure of the quality of the road at KM 12.7 Johor Bahru-Skudai, namely the high traffic level at peak times and because of the lorry carrying excessive loads.

There are two types of failures, namely malfunctions and structural failures. Malfunctions occur when the guide is uncomfortable and it is difficult to control the vehicle due to the pavement surface being too rough, changing, or slippery. The change in the shape of the pavement may be caused by ineffective runoff water drainage, poor surface-wearing course, and lack of periodic work maintenance. The problem with the road becoming slippery is that the surface becomes polished after the surface is used for a long time. The road skid resistance also quickly deteriorates if the premix mixture (concrete mixture or bitumen is not in good condition during construction, which causes the melt). Excessive or unwary use of binders in premixes can make the surface bonded.

Road pavement is considered to have structural failure due to bearing excessive traffic loads, an improper mixture of premixes and lethargy will cause fracturing, loss of original surface shape, and the occurrence of a pothole (Gosh, Debaroti et al. 2018). The failures, whether longitudinal, transverse fracturing, or alligator cracks, come from subgrade failures and pavement materials. Changes in a form such as settlement occur due to the pressure of assertiveness rather than traffic load. The road surface may be loosed and unlatched due to the cavity or air bubble between ingredients of binding material or bitumen. The failure that occurs along the road may be different depending on the weather, traffic loads used, and construction quality. According to the study of Maeda et al. (2020) in Japan, the type of linear crack failure classification is caused by several factors, including longitudinal load and construction joints. There are types of ruptures found, such as lateral cracks, crocodile cracks, rutting, bumps, potholes, types of pipes/separators, and blurred/missing zebra paths. Another study found the pothole failure on the asphalt pavement. The shape of the road pothole is like a bowl caused by moisture deterioration (She, Xin et al. 2021). The average diameter of pothole is 200 mm -1000 mm. If the pothole's width is below 200 mm, the patch technique does not involve cutting work, but if the pothole's width is up to 1000 mm, it requires a road-cutting method before overturning it. To get a clearer view, Figure 1 show the type of failures that usually occurs on the road surface.


a) Pothole


b) Linear longitude cracking


c) Lateral linear cracking


d) Crocodile Cracking


e) Slipping


f) Weevil

Figure 1: The type of ruptures

The observation of local situations and resources found three problems in the study focusing on maintainances work for the road surface. First, more research and development studies must be conducted on the patching innovation of road failures in cold asphalt. The design of the patch mixture using waste material in emergency maintenance work is also very minimum information. The last one is that it is tough to find a study on verification or the quality of patch material in a field during the road resurfacing or patching practical. The paper's objective is to produce a new solution for a pothole patching premix design using the application tools, Response Surfaces Method. Therefore, this study will focus the road patching using a new modified binder and waste material as an alternative to save the environment. By using the new premix, the patching process will be fast and easy to handle. The innovation of modified premix in this paper differed from the previous studies by using recycled material; the inner tire tube and the binder use cold asphalt instead of hot asphalt, which can reduce the preparation time. The scope of the writing is also limited only to pothole failures and patching premix design.

2.0 Literature Review

Since the last century, innovative studies have been carried out on patching materials in bitumen to improve the durability of road asphalt. The study will consider adopting new materials for Malaysia's hot, humid weather, the burden of traffic capacity and driving styles, and using the source and natural materials locally. Studies by Riza Atiq and colleagues (1997) have examined the smoothing of latex mixtures into concrete asphalt pavements. The percentage of added ingredients of 3% and 6% latex in bitumen was selected and compared. The result indicates a latex content of 3% of the pavement because of its ability to increase stability in the Marshall Test from 7.7kN to 13.5kN, up to 54.72%. In comparison, latex 6% increases Marshall's stability by only 12.17%. However, it was identified that latex 3% increased the optimum bitumen content by 1.77% compared to latex 6%, which decreased the optimum bitumen content by 4.95%. The latest potential use of latex and the stage of effectiveness of the material were studied by investigators Mahsuri et al. (2021). The qualitative method was used as an approach, and the head of this study focused on the highway on Jalan Persekutuan Yong Peng – Segamat from Kampung Desa Temu Jodoh to Kampung Kwong Sai, Segamat. The results of this study show that the use of latex in road construction can reduce the problem of road rifts that occur after using the original latex mixture method into asphalt to improve the quality and quality of highways in the study area. Studies of the effectiveness of the material need to be carried out on the road surface after application.

Kulian and Mokhtar (2021) in their study used blasting waste material (explosion residue) in a mixture of highway pavement to see the potential of the material. They make a mixture of explosive residual ingredients as an added ingredient in the bitumen mixture by 0%, 5%, 10%, 15%, and 17%. The result showed that 10% of the remaining explosion content was the optimum value because the stability value of 82.5kN was higher than the control sample of 37.7kN. For flow values and Marshall Quotient values as well, they are 4mm and 20kN/mm, respectively. The following study is the design of blasting waste mixture through aggregate analysis to test the magnitude of the air capillary in the mixture. The result shows that too little capillary in the mixture causes bitumen in the pavement to melt, and the road surface will be less in skid resistance and harmful to the user. On the other hand, if the magnitude is too high, it can affect traffic load.

Furthermore, Ahmad Nazrul Hakimi Ibrahim and colleagues originally carried out the study of aggregate dressing materials, namely bottle glass, liquid-crystal display glass (LCD), and recycled plastic (2018). Investigators used approximately 5% of the aggregate material in asphalt pavement. Samples have been tested according to the characteristics of the performance of the asphalt mixture in terms of the stability and flow parameters of Marshall, Marshall Quotient, modulus capability, and dynamic progression. The replacement ratio of 1% of the original cycle plastic and 4% of the original cycle glass showed an equivalent and consistent result compared to the control sample and other sample ratios for all tests.

Khairul (2016) has studied the Crack Relief Layer (CRL) layer, which is placed as a cushion between the new and old pavement to block the pressure and movement of the new layer of pavement. CRLs are usually used for pavement on airfields, and their primary function is to block cracks. CRL samples have been tested using the Marshall test to determine their parameters, such as shedding, stability, flow, and capillary content in the amount of the mixture. They are filled with bitumen and Resilient Modulus (RM). The results show that 3% of bitumen is the most suitable percentage for CRL. The CRL layer has a high RM value which indicates good pressure absorption efficiency and can prevent cracks from spreading to the surface and is also subgrade. This assessment is critical to support these innovations.

Gosh, et al. (2018) reported the assessment of the work after the pothole patch. The investigation from the respondent stated the failure to organize the patched pavement if the patch was constructed repeatedly. The results of the study also stated that the complaints of ordinary people had triggered the activity of road repairing of potholes due to surface lethargy and weather. The maintenance commonly used to repairs is throws and roll, and the most widely used material is hot mix asphalt. From the study, the suggestion for the financing allocation needs to be prioritized for the staff, equipment, and maintenance materials.

The pavement mixture material used for the road is Hot Mix Asphalt (HMA) with an aggregate mixture ratio (approx. 94% - 96%) and an asphalt binder (4% - 6%) of the total weight of the mixture. Cold mix, cold emulsion mix, or generic stockpile mix refers to an asphalt mixture provided in a great state. For Cold Mix Asphalt (CMA) mixtures, added materials such as cement are used to improve the characteristics of mixed materials that use bitumen emulsion. Customized CMAs have a low homogeneous level and require a more extended curing period to achieve optimum strength. The CMA modification is by adding Polyvinyl Acetate Emulsion (PVAC-E), which can increase the pressure strength by up to 31% compared to the unmodified CMA (Tisara Sita, 2021). In addition to the mixture above, there is a mixture of warm mixed asphalt (WMA). Gosh, et al. (2018) compare hot and cold premix pavement mixture procedures, as shown in Table 1. They use simulation and mixed procedures to study potholes, whereas the parameters in the procedure are altered according to the expertise. There are strengths and weaknesses between the two in the test conducted. The study shows that the tire track of the pavement surface's upper wheels continues to increase with the vehicle load when using a cold premix. Sealed for the patching of the cold premix has the effect of cracks at the edges if the surface is wet and lacks periodic maintenance work. The hot premix shows that the standard performance of compaction of the fixing is better for deep potholes.

Table 1: Specification of patch procedure

Ingredients/ Parameters	Compaction	Pavement Supplies	Pothole Edge	Depth of pothole
Hot premix (HMA)	Standard	Clean and there is a tack coat	No coating patches	Shallow (25mm)
Cold premix (CMA)	Weak	Less clean and wet	There is coating patchwork	Deep (40-50 mm)

Source: Gosh, et al. (2018)

2.1 Empirical Case of Road Surface Maintenance Portal

The portal etapong (2022) presents the maintenance work information related to patching potholes on the road surface for minor roads in Terengganu. The portal was developed by the company of Permint Granite-HCM Sdn. Bhd. There are four main menus: Introduction, Pothole, System, and Company. The first menu, the introduction, displays the scope of the maintenance work carried out, while the second menu focuses on pothole failure procedures. The failure may be selected because of the highest risk to road users compared to other failures. The current procedure of the pothole maintenance work process has been elaborated in depth. The process is to ensure the current traffic conditions when the road closure work is carried out, marking the perimeter of the pothole area at least 150mm in a square shape, and then cutting is made according to the marking line. Next, the area and the pothole are cleaned and dried. The surface of the pothole should be sprayed with RS-1K grade tack coat 0.25-0.55 liter/m^2 and left for approximately 30 minutes before patching with asphalt premix, where each layer of not less than 4 inches will be compacted. Premix of the hot mix or cold mix type is used in compliance with specifications references: JKR/SPJ/1988 –Table 4.10. The patching procedure starts with measuring and marking, cutting the failure pothole with a square shape, patching, and then labeling. The e-tapong system contains submenus info, maintenance, complaints, and reports. The last menu is about the company that manages the maintenance work.

The news utusanborneo.com.my (2017) reported that the Ministry of Kerja Raya Malaysia (KKR) and the Malaysian Latex Institute (LGM) have collaborated to carry out a new pavement study called Cuplumb Modified Asphalt (CMA). The pavement binding material comes from two sources, the form of liquid (latex) or lump (cup granary), the natural scraped material. Also, the use of recycled material either used latex gloves was wasted. The CMA economy uses approximately 4.2 tons of lump latex per kilometer (6000 $metres^2$) for resurfacing the road. The site has been selected based on the road failures such as cracking, rutting, surface delamination, stripping, and excessive patching. This CMA project was carried out in 4 selected locations: Jalan Gemas Rompin, Tampin Region, Negeri Sembilan, Jalan Gerik Kupang, Baling Area, Kedah, and Jalan Kuala Lumpur Kuantan, Temerloh Area, Pahang. When The Yong Peng Segamat Fellowship Road from Temu Jodoh

Village to Kwong Sai Village, Segamat was categorized as a rebuilding project using the natural latex mixture of cup lumps as an added ingredient in the asphalt mixture (CMA) showed its layer courses as in Figure 2. Based on preliminary observations, the general CMA study showed a positive effect and hopefully can improve the durability of the road surface.

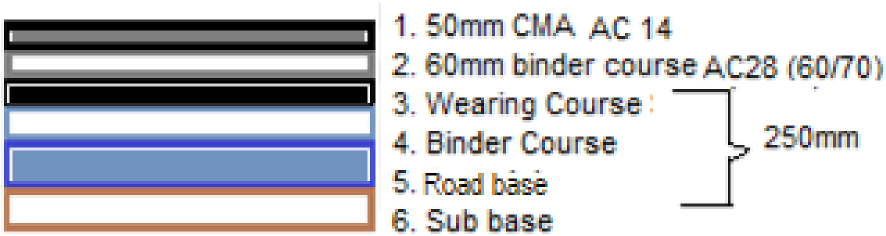

Figure 2: Layer 1 & 2 asphalt mixture (CMA) is patched on top of the road
Source: JKR (2018)

A portal bituchem.com (2016) presents information on the maintenance and repair of roads using air patch system technology using machines and trucks around the United Kingdom. The sharing of information on their platform is related to the experimental process that has been carried out. The maintenance of the road potholes using a technology that is easy to move and practical, namely a spray tanker. The first process is initiated by improving the deformation level of the pothole surface. After that, the aggregates emulsions with polymers filled into the pothole. The manual method is used during the process to reduce traffic safety risks.

The other website that shares innovation in pothole patching is americanroadpatch.com. The portal explains that revamping the road on the pothole takes a short time. The repair process begins with the package of premix material inserted into the pothole. It is effortless to handle whether the premix is slurry or lump. Afterward, the compaction and cleaning process is carried out before spreading or attaching the sheet of a patch to the surface of the pothole.

3.0 Materials and Methods

The method flow of this study uses the design thinking method to initiate the real problem and get the idea for innovation to solve the problem of users. Then to design the material mixture or ratio, Response Surface Methodology (RSM) is applied so that the premix ratio can be controlled according to the model. The premix can be mixed and tested in the laboratory from the model design to get the verification.

3.1 Raw Materials

Most patch repair mortars fall into two categories, the mortars based on organic binders (epoxy resin or polyester) and those based on inorganic binders like Portland cement. and an aggregates, silica fume, fibers and other additives. The premix for patching potholes in this study will use modified binder (cold asphalt) and bicycle tube tires.

3.2 Design & Testing

The study used the design thinking method; Empathize: investigating the road failures and high-risk users such as motorcyclists, Define: stating the issues and problems of road surface failure. Ideate: throwing out ideas and hypothesizing the patching material that can be used very fast and available to solve the late action of maintenance; prototype: fostering solutions as new modified patching premix; and Test: testing to verify solutions.

Four road samples have been selected randomly to prove that road failures occurred everywhere and that maintenance takes a very long time to improve the ruptures. Each road is observed by taking approximately a distance of 5km per road, which was taken on April 3-5, 2022, until July 1, 2022.

After finishing the development of the prototyping project, the pilot studies were run to assess the expected hypothesis; the last stage was testing for verification. Figure 3 shows that the project process flow begins with obtaining information from related studies, producing innovations, and verifying the project.

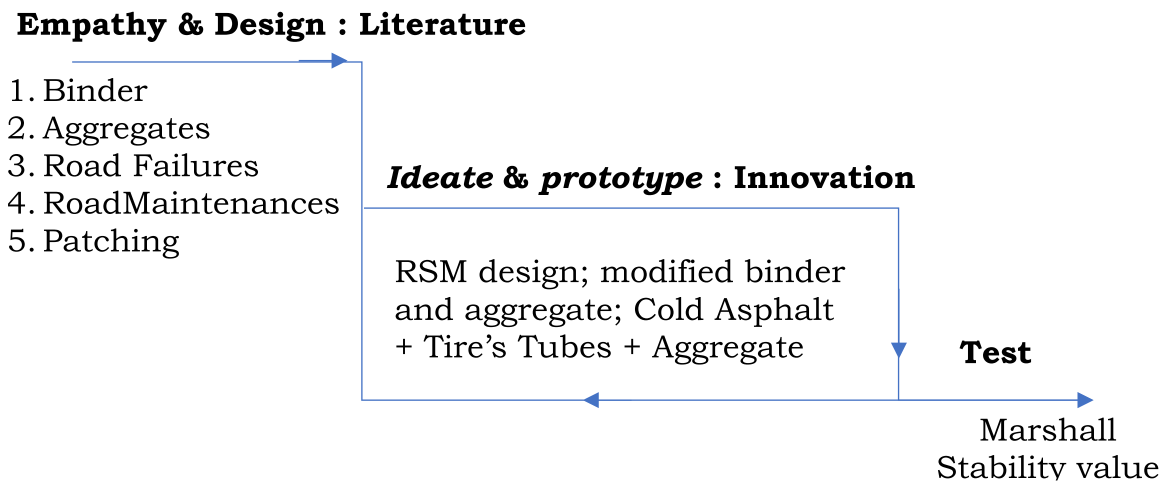

Figure 3: Flow of study

The design for the ratio of premix material mixtures uses the Response Surface Methodology (RSM) application, Design Expert (V13.0). This study applied RSM to analyze the Marshall's stability (MST) in response to modified binding material (BI), the aggregate (AG) and the volume (V). Table 2 shows the three-factors where the higher and the lower levels of modified binding material (BI) and the aggregate (AG) was set as 3–6 % and 94–97%, respectively. The volume was set as 2-4 m^3. The design with five replications for center points included 15 runs. The regression plus interaction effect was fitted to the measured data and the significance of linear, quadratic, and polynomial interaction terms for all responses were tested by performing analysis of variance. The best model could be used base on their fit and significant result.

Table 2: The 15 runs of factors and response

Std	Run	Factor 1	Factor 2	Factor 3	Response 1
		A: BI (%)	B: AG (%)	C:V(m3)	MSt (kN)
11	1	6.5	87.6137251	2.5	24
15	2	6.5	93.5	2.5	27
8	3	10	97	3	20
9	4	0.61372509	93.5	2.5	25
12	5	6.5	99.3862749	2.5	30
6	6	10	90	3	35
2	7	10	90	2	21
10	8	12.3862749	93.5	2.5	24
1	9	3	90	2	25
3	10	3	97	2	26
7	11	3	97	3	20
13	12	6.5	93.5	1.65910358	23
14	13	6.5	93.5	3.34089642	26
5	14	3	90	3	29
4	15	10	97	2	18

4.0 Result and Discussion

The result for the design of patch tires using the RSM application, the published model for the premix mixture ratio equivalent for this study is the cubic model ($ax^3 + bx^2 + cx + d$) i.e.;

$$MST=27.19 -0.297A +1.78B +0.892C -1.25C-1.25AB +2.25AC -2.75BC -1.14A^2 -0.261B^2 -1.14C^2- 0.25ABC -5.03A^2B +0.858A^2C -0.4527AB^2$$

[x:A=BI=binder(%), B=AG=aggregate(%), C=V=volume(cm^3),
y:MST=Marshall stability (kN)]

Thus with this model, the actual ratio of the mixture can be correctly calculated for the specified design value. Figure 4 shows a model graph in 3D form with a standard deviation reading (SD) of 1.75. A low SD indicates that the model is good. The result of R Squared 0.9886 and adjusted R Squared 0.8404 indicate an ideal model that shows the response has a corresponding correlation between the variables.

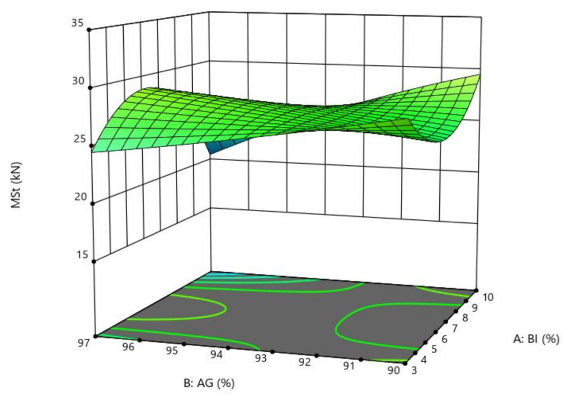

Figure 4: A 3D cubic model for patch design ratio

5.0 Conclusion

The study's objective was achieved using the design thinking method to produce innovation, while RSM was to obtain an optimum mixed design model. RSM is supported in multivariate Taylor series expansion, that is in this study, a cubic polynomial gives a fit and significance to the parameter selected instead of linear and quadratic model. The robustness of this study is applied to the materials from localities and reusing very low-cost recycled materials. However, the scope of the innovation study is limited to minor pothole failure only. In the study on patch materials, there were also areas for improvement in maintenance management, especially in domestic studies. There are examples in past studies from overseas that road surface failure has shifted to integrating new technology for its maintenance management. Therefore, in the future study, it is recommended that road management patching using the latest technology to relocate the ruptures on the road. The project implementation can also be observed after the patching process with the current circumstances, such as traffic load and weather conditions. The assessment of the actual results of pavements using latex should be carried out. This is because the issue of road failures will rise due to the deterioration and the traffic load capacity. The constraints also may be due to the high-cost allocation, lack of competence or skilled human resources in maintenance, the cycle of road life that has exceeded the construction design, limited time construction with congested road conditions and the weather, and the increasing road traffic capacity every year. Identifying innovative solutions, such as using potential, functional, and durable pavement patching materials, can minimize the problems and maximize the safety of road users.

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