Journal of Inventive Engineering and Technology (JIET) Vol 1 Issue 2 January 2020

Journal of Inventive Engineering and Technology (JIET)
ISSN: 2705-3865
Volume-1, Issue-2, January, 2020
www.jiengtech.com
Research Paper Open Access

EMPIRICAL POST-MORTEM ANALYSIS AND HEALING APPROACH OF FLEXIBLE AND RIGID PAVEMENT FAILURES IN ANAMBRA STATE

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ABSTRACT*: The early failure of pavement in some major cities of Anambra state has been of much concern. The paper examined the possible causes of the failure of three (3) roads in three major cities of the state. The cities are Awka, Onitsha and Nnewi. Cored asphalt samples and concrete samples were taken from failed portions of the pavement to examine the asphalt properties and compressive strength of the concrete samples respectively. For the asphalt samples, bitumen extraction tests and binder gradation tests were carried out. Marshall Stability of the asphalt are adequate in each case but the flow are outside of specification limits. The bitumen content by weight of aggregate is beyond specification limits in all the samples. The binder gradation shows the aggregates used falling outside the grading envelope. The compressive strength tests also show the strength of the concrete below specification limits. Four pathological healing processes of healing flexible pavement with flexible pavement, healing rigid pavement with rigid pavement, healing flexible pavement with rigid pavement and healing rigid pavement with flexible pavement were proposed.*

KEYWORDS*: Flexible pavement, Cracks, Pavement failure, Traffic loads, Structural design, Marshall Stability, Binder, Aggregate, Flow*

Date of Submission: 16-02-2021 Date of acceptance: 19-02-2021

I. INTRODUCTION

The failure of flexible is usually associated with environmental conditions and traffic loading. The influence of environmental conditions and traffic loading are often targeted to be managed through pavement design that involves mix design and structural design (Brown, 1993; Sorum et al, 2014; Hadian, 2019). However, the human error and shortcomings in this process among other factors often account for early failure of pavement. This is usually the case in Nigeria where Ezeagu (2018) showed that poor design, poor workmanship, use of low quality and substandard materials among other related factors account for most of the early failure of pavement in Nigeria. According to Hesp et al (2009), some pavements perform either better or worse than expected. They attributed this behaviour to the variations in subgrade thickness, pavement design, climate, traffic level and other elusive factors. These factors introduce deterioration and distresses within the pavement structure (Fahkri et al (n.d) often leading to premature cracking. Premature cracking is expensive costwise and servicewise because they lead to shortened pavement residual life and contribute to rougher ride (Gavin et al, 2003; Hesp et al, 2009). Regular maintenance of pavement is a time and cost-consuming process. However, it is an indispensable duty because of the importance of pavement in the society. According to Fahkri et al (n.d.), the evaluation of pavement condition is based on two key indices; technical indices and structural indices. While technical indices looks at the surface roughness and skid resistance, the structural indices looks at the capacity of the pavement to bear imposed traffic loads.

Owing to increasing volume and weight of traffic loads which have caused flexible pavement to fail early (Hadian, 2019), the risk of premature failure can be minimized by using the best practice in the planning, designing, construction and maintenance of the pavement. This can be achieved by examining the pavements that failed prematurely with the focus of determining the causes of failure and guarding against such in the future (Zumrawi, 2015). One of the ways of examining causes of failure in pavement is structural assessment. Structural assessment of pavement is critical to developing proper maintenance treatment for a given pavement. This can be done using destructive and non-destructive methods of tests. According to Hu (2015) non-destructive methods such as falling weight deflectometer (FWD) and ground penetrating radar (GPR) are used to assess pavement and foundation layer properties. FWD is used to measure pavement and foundation layer moduli values with inputs of layer thicknesses obtained from GPR measurements. Destructive methods basically involve coring of the pavement to obtain samples which are then taken to the laboratory to carry out tests.

The failures of pavement in major cities in Anambra state, south-eastern Nigeria has become a worrisome occurrence because most of the roads fail earlier than expected. The failures of these pavements manifest in different forms. Among the commonest are fatigue cracks, multivariate cracks (Fig.1), high severity cracks (Fig. 2), medium severity cracks (Fig.3) and low severity cracks (Fig.4).

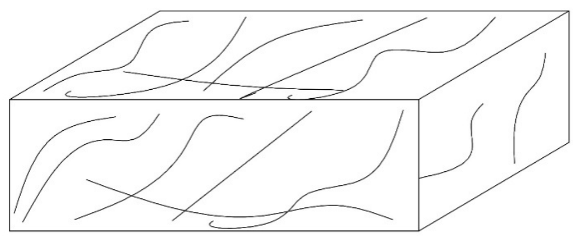

Fig. 1: Multivariate cracks

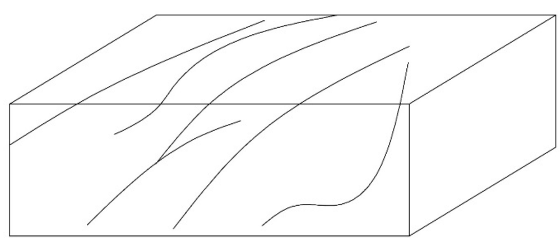

Fig. 2: High severity cracks

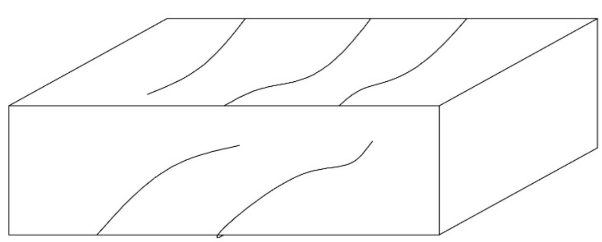

Fig. 3 Medium severity cracks

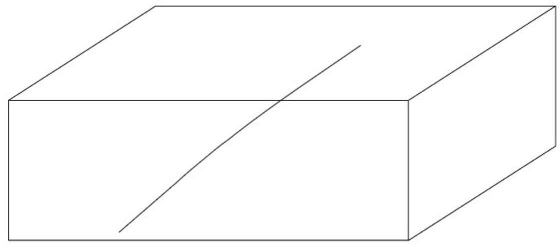

Fig. 4: Low severity cracks

These cracks when not treated soon leads to potholes and complete failure of the road. To find out the cause of these cracks, it is necessary to carry out a post-mortem analysis of failed asphalt to examine their technical specifications and to discover the causes of failure in order to prevent against the occurrence of such in the future. The paper investigated and analysed the cracks and failure progression in pavement and structures by crack investigation mechanism. The paper also proposed methods by which these cracks can be healed in order to provide a stable pavement structure.

II. MATERIALS AND METHODS

Section A and B show the materials used in the research and the method adopted for the research respectively.

A. Materials

The pavement materials used for the study were obtained from three major cities in Anambra state. The cities are Awka in Anambra central Senatorial district, Onitsha in Anambra north Senatorial district and Nnewi in Anambra south Senatorial district. The choice of these cities is significant because they are the busiest and most densely populated cities in Anambra state. It is expected that what could be feasible in those cities, can also be applied successfully to other smaller and less populated cities in the state. Two cored asphalt samples were collected from the failed portions on one road in each of the cities. The roads are Awka-Amawbia road in Awka, Holy Trinity 3-3 road in Onitsha and Nnewi-Oba road in Nnewi. The cored samples were taken to Anambra state materials testing laboratory (ASMTL) for laboratory analysis. Samples were also collected from rigid pavement portions in these cities to examine their compressive strength.

B. Methods

The methods adopted in the study involves the examination of the properties of cored asphalt samples from failed portions of the flexible pavement and determination of the compressive strength of materials taken from failed portions of the rigid pavement.

Laboratory tests carried out for the flexible pavement in view of this include bitumen extraction tests, Marshall Stability tests, flow, void and bulk density of asphalt. Bitumen extraction was done in accordance with ASTM 2171-88. Marshall Stability and flow were done according to ASTM D 1559 while bulk density test was done according to ASTM C 29. Sieve analysis of aggregate was also carried out to see whether they fit to limits. Compressive strength tests were also done for the rigid pavement materials in accordance to ASTM C 39.

III. RESULTS AND DISCUSSIONS

Based on the laboratory tests carried out, the discussion would consider the binder grading envelope, asphalt test results, bitumen extraction test results and compressive strength test results.

A. Binder grading envelope

The sections I, II and III and Figs. 5 – 7 show the binder gradation of the three roads respectively.

I. Awka-Amawbia Road, Awka

Fig. 5 shows the binder gradation of Awka-Amawbia road. As stated earlier, the samples were collected from two failed portions of the road. From the grading curve, it can be seen that the aggregate grading did not fit well into the grading envelope especially the fines. There is also a lot of inconsistency in the between the aggregate grading of the two cored asphalt samples. The implication of this could be a porous asphalt because the gap created by the aggregate were not filled by suitable sized fillers. A porous asphalt is liable to cause early failure because of the entrance and percolation of water in the pores and poor transfer of inter-particle stresses.

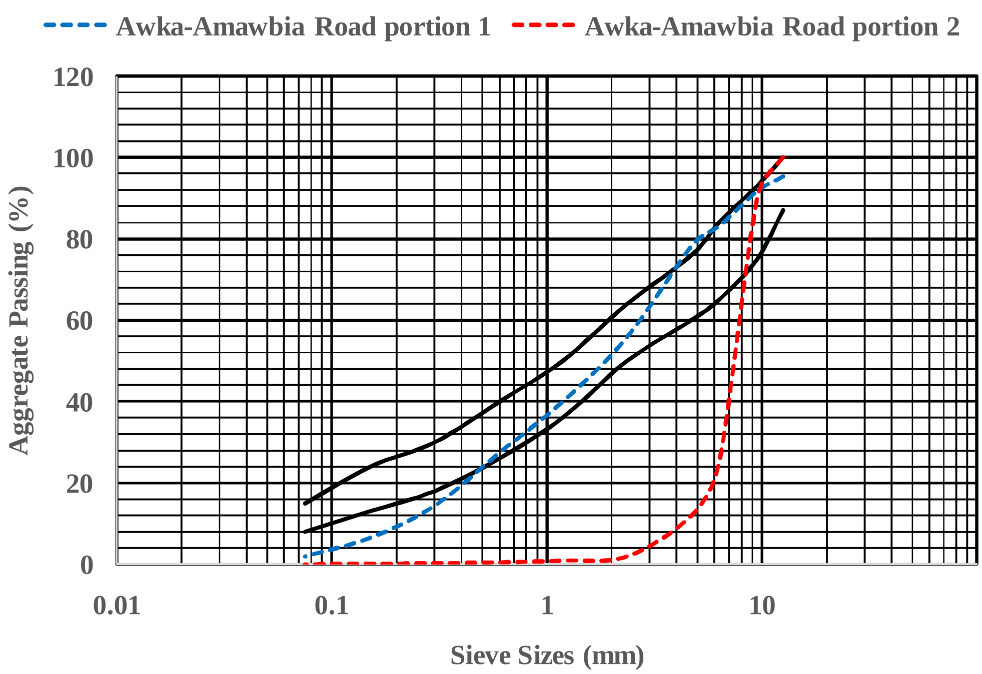

Fig. 5: Binder gradation for Awka-Amawbia road

II. Holy Trinity Road, Onitsha

The filler component of the aggregate used in the preparation of asphalt used on Holy Trinity road is also not impressive. Almost 50% of the aggregate used fall outside the acceptable grading envelope in portion 1 while in portion2, the situation is worse. The aggregates are very poorly graded and thus unable to bind together properly under load and thus collapse and failure of the road.

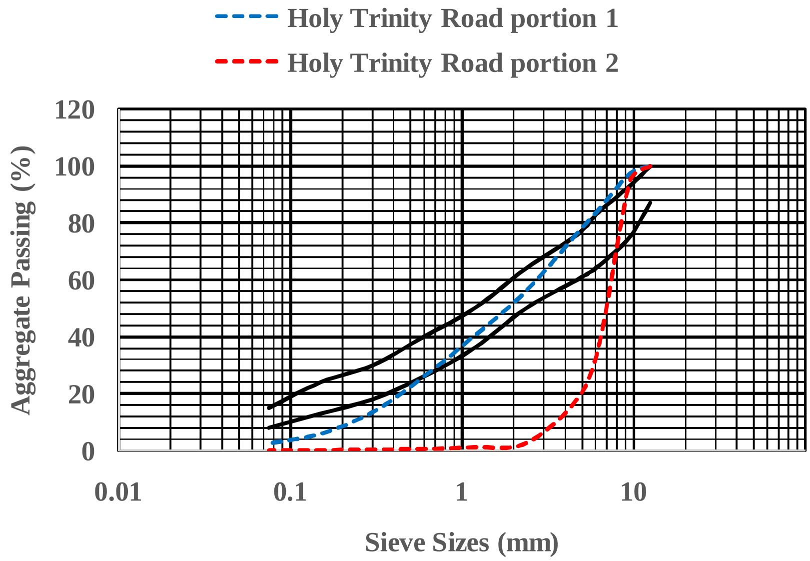

Fig. 6: Binder gradation for Holy Trinity road

III. Nnewi-Oba Road, Nnewi

More than 50% of the aggregate used fall outside of the acceptable grading envelope in portion one of the pavement. In portion 2, more than 80% fall outside the grading envelope. This shows that the aggregate used for the pavement is not well-graded according to specification and this must have contributed to the earlier failure of the pavement.

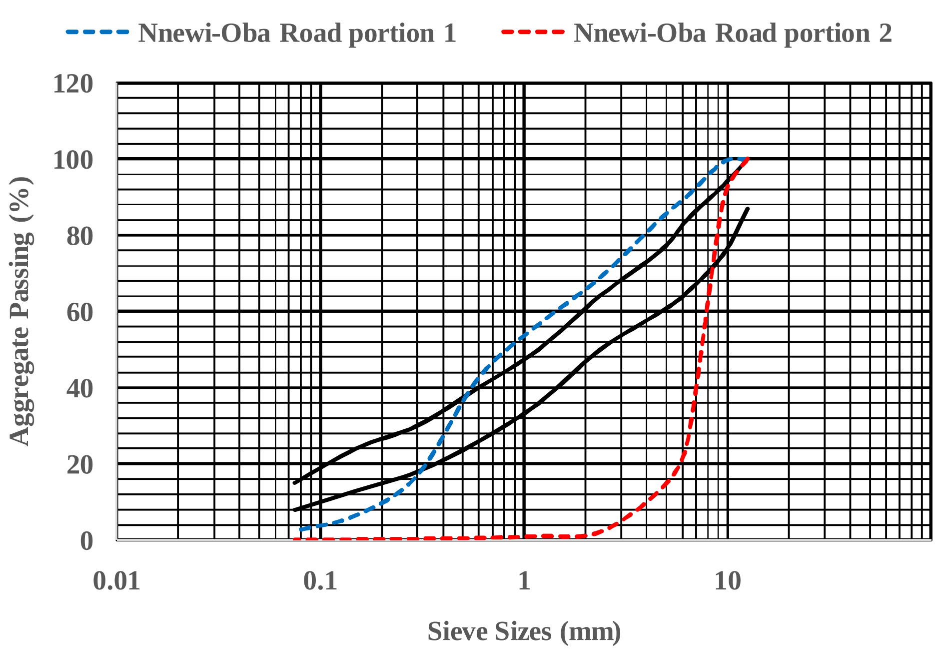

Fig. 7: Binder gradation for Nnewi-Oba road

B. Comparison of binder gradation for the three road

Figs. 8 and 9 show the binder gradation of the three roads and locations on each road in comparative manner. In Fig. 8, the Nnewi-Oba road falls well out of the grading envelope. In Fig. 9, the binder gradation of the asphalt falls out well from the grading envelope more significantly and almost in similar manner. The curves are similar and it seems like the asphalt are from the same source. Effort and care should be used in the design, mixing, transportation and laying of asphalt to ensure all meet specification limits and to avoid early failure of pavement.

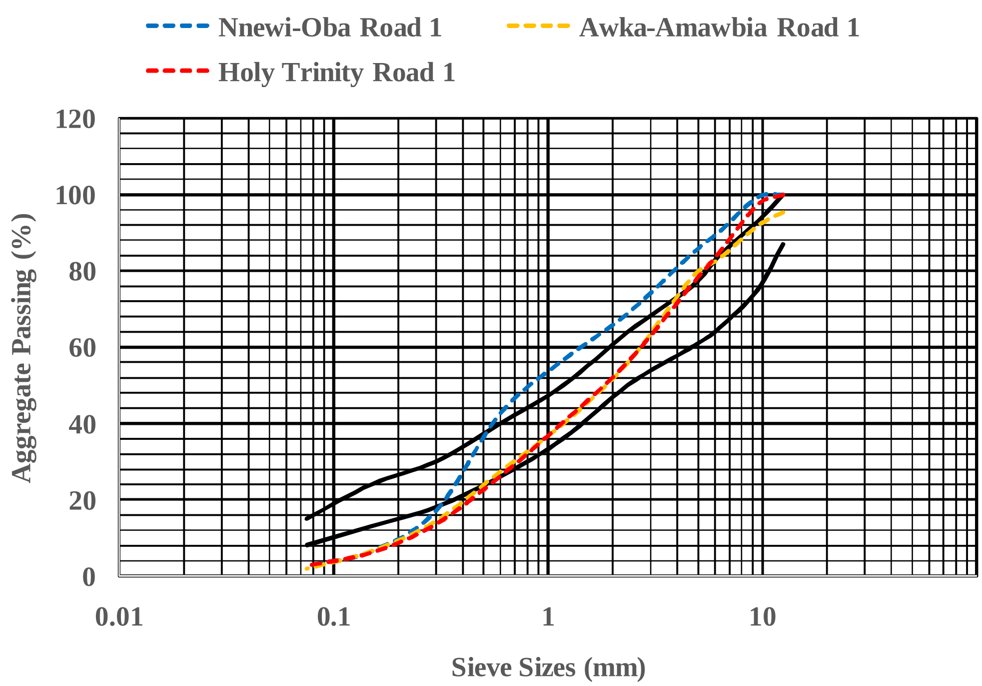

Fig. 8: Binder gradation for location 1 of the three roads

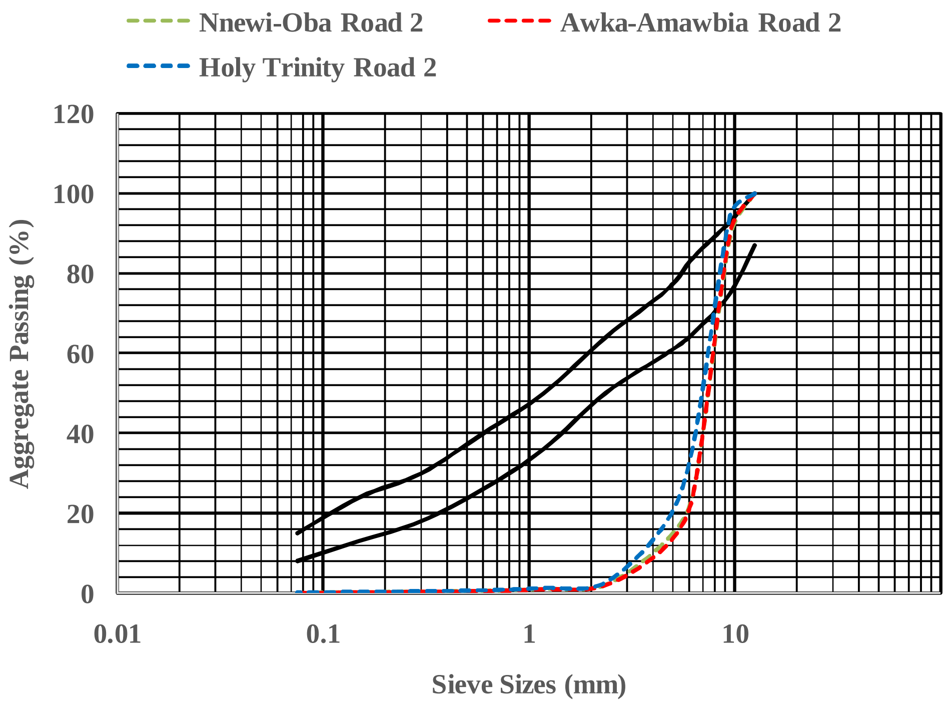

Fig. 9: Binder gradation for location 2 of the three roads

C. Bitumen extraction test results

Fig. 10 shows the bitumen extraction apparatus and the laboratory extraction tests ongoing on the cored samples. Table 1 shows the summary of the tests results together with specification limits applicable while Tables 2 – 4 shows the results of bitumen extraction from the asphalt.

Fig. 10: Bitumen test apparatus

Table 1: Test results of cored samples

Location	Layer thickness (mm)	Marshall Stability (kN)	Flow (mm)	Bulk Density (g/cm^3)	Voids filled with bitumen (%)	Total void in the mixture (%)
Awka-Amawbia Road	63	28.194	4.01	2.338	111.6	-2.6
Holy Trinity 3-3 Road	65	17.782	1.77	2.304	102.6	-0.6
Nnewi-Oba Road	60	21.504	1.83	2.258	113.9	3.5
Specification Limits		> 3.5	2 - 4	2.3	75 - 82	3 - 5

From Table 1 above, the average value of bulk density for Awka-Amawbia road is 2.338g/cm3. The Marshall Stability value is 28.194kN with a flow of 4.01mm. This is an indication that the compacted mix cannot be distorted or be displaced under a load of 28.194 kN. The voids filled with bitumen and total voids in the mixture are all beyond the specification limit. This must have contributed to the earlier failure of the pavement. For Holy Trinity road, the Marshall stability is 17.782 kN with a flow of 1.77mm. The voids filled with bitumen and total void in mixture are also beyond specification limits. For Nnewi-Oba road, the Marshall stability is 21.504 kN with a flow of 1.83mm. The void filled with bitumen is beyond specification limit while the total void in mixture is within specification limit. Generally, for the three roads, most of the parameters tested are outside the specification limits and this must have contributed to the early failure of the pavement. There should be improvement on the aggregates and bitumen to be used for asphalt pavement in order to meet the required specification. The workability should be maintained to facilitate placement of the mix without segregation.

Table 2: Aggregate and fillers from extraction of binder content for Awka-Amawbia Road

Location	Weight of asphalt (g)	Weight after extraction (g)	Difference (Bitumen) (mm)	Aggregates (%)	Bitumen by total weight (%)	Bitumen by weight of aggregate (%)
Awk-Amw Location 1	901.54	802.05	99.49	89	11	12.4
Awk-Amw Location 2	915.74	884.03	31.71	96.5	3.5	3.6

Table 3: Aggregate and fillers from extraction of binder content for Holy Trinity 3-3 Road

Location	Weight of asphalt (g)	Weight after extraction (g)	Difference (Bitumen) (mm)	Aggregates (%)	Bitumen by total weight (%)	Bitumen by weight of aggregate (%)
Holy Trinity Location 1	686.57	613.73	72.84	89.4	10.6	11.9
Holy Trinity Location 2	919.05	843.46	75.59	91.8	8.2	9

Table 4: Aggregate and fillers from extraction of binder content for Nnewi-Oba Road

Location	Weight of asphalt (g)	Weight after extraction (g)	Difference (Bitumen) (mm)	Aggregates (%)	Bitumen by total weight (%)	Bitumen by weight of aggregate (%)
Nnewi-Oba Location 1	798.05	684.56	113.9	85.8	14.2	16.6
Nnewi-Oba Location 2	951.32	946.08	5.24	99.4	0.6	0.6

The aggregate content of the asphalt and the bitumen contents of the roads are shown in Tables 2 – 4. Hot mix asphalt (HMA) has specification limit for percentage bitumen content by weight of aggregate to be between 5.0 – 8.0% (General Specification for Roads and Bridges, 1997). The values of bitumen content by weight of aggregate for all the roads fall outside the acceptable range. For Awk-Amw, the bitumen content by weight of aggregate for location 1 and 2 are 12.4 and 3.6 respectively. There is wide disparity between these two values but they are supposed to be same or within close range since the samples are collected from the same road. The same trend applied for cored asphalt samples collected from Holy Trinity road and Nnewi-Oba road. The quantity of bitumen is in some cases more than required and in others less than required. The differences could be due to failure to heat asphalt and aggregate at the required temperature which leads to segregation.

D. Compressive strength test

Compressive strength test was carried out for paving stone used as rigid pavement at the three locations. The results are presented in Table 5 below. From the results one see that the three compressive strength are all below the expected design strength. This must have accounted for the early cracking and failure that occurred in the pavement.

Table 5: Compressive strength test results of the three locations

S/N	Parameters	Awka-Amawbia Road	Holy Trinity Road, Onitsha	Nnewi-Oba Road, Nnewi
1	Cross sectional area (mm^2)	2000	2000	2000
2	Volume of kerb (m^3)	0.0013	0.0013	0.0013
3	Mass of kerb (kg)	2.65	2.65	3.00
4	Density of kerb (kg/m^3)	2038.46	2038.46	2307.69
5	Maximum crushing load (kN)	218.40	126.30	160.70
6	Compressive strength (N/mm^2)	10.9	6.3	8.0
	Specification Limit (Design strength, N/mm^2)	$\geq$15	$\geq$15	$\geq$15

E. Healing approach

Having discovered the causes of early failure of flexible and rigid pavements in preceding sections, it is proper to guide against these by proper design of flexible and rigid pavement. In situations where the pavement has already failed, reinstatement becomes inevitable. It has been common practice to reinstate failed flexible pavement with flexible pavement and failed rigid pavement with rigid pavement. The paper tends also to propose two additional means by which failed pavement can be reinstated. Four possible means of pathological healing or reinstatement of pavement proposed are shown in Fig.s 11 – 14. In Fig. 11, the flexible pavement can be healed with flexible pavement which is usually a common approach. Just as the flexible pavement, rigid pavement is usually healed with rigid pavement as shown in Fig. 14.In Fig.s 12 and 13, it is possible to reinstate rigid pavement with flexible pavement and flexible pavement with rigid pavement respectively.

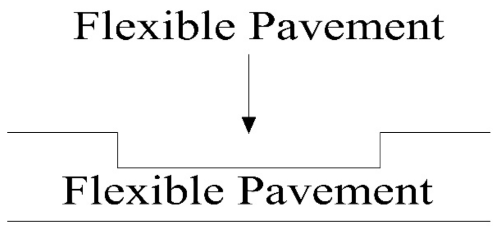

Fig. 11: Healing of failed flexible pavement with flexible pavement

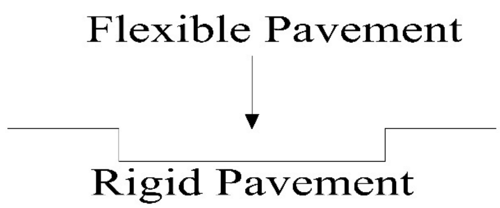

Fig. 12: Healing of failed rigid pavement with flexible pavement

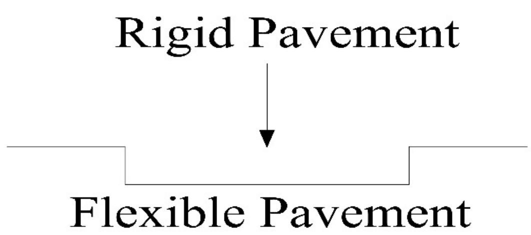

Fig. 13: Healing of failed flexible pavement with rigid pavement

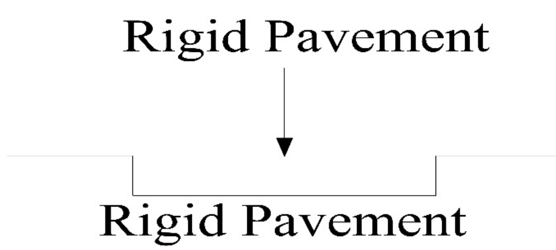

Fig. 14: Healing of failed rigid pavement with rigid pavement

IV. CONCLUSION

Investigation was carried out to discover the causes of the failure of some flexible pavement in three senatorial districts of Anambra state in the cities of Awka in Anambra central Senatorial district, Onitsha in Anambra north Senatorial district and Nnewi in Anambra south Senatorial district. Destructive testing method was used and cored samples obtained from the sites where tested. Tests done included sieve analysis, asphalt tests and bitumen extraction tests. Results from the tests showed that in most cases that the aggregate used were not within the grading envelope. The properties tested for the asphalt show that most of them are outside the specification limits. The bitumen content by weight of aggregate is inadequate in all the samples tested. The compressive strength test result also shows that the concrete elements are below the specification limit. These shortcomings must have contributed significantly to the early failure of the pavement. Four pathological or healing process was proposed to reinstate failed pavements. These are healing of flexible pavement with flexible pavement, healing of flexible pavement with rigid pavement, healing of rigid pavement with flexible pavement and healing of rigid pavement with rigid pavement. The processes are outlined in the body of the work.

V. CONFLICT OF INTEREST

There is no conflict of interest associated with this research work.

VI. ACKNOWLEDGEMENT

The authors wish to thank the management of Anambra state materials testing laboratory for their assistance in carrying out the tests.

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