EFFECT OF NUMBER OF CLASSES IN A VISUAL RATING FOR SULPHATE ATTACK

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ABSTRACT

Visual observations are considered as an important first step in the assessment of performance of the materials under sulphate attack, in laboratory experiments and during field studies. Correlations of visual observations, supported by other tests, during controlled laboratory experiments and conditions in the field are essential to assess the performance of materials in the field. Many visual ratings have been used and proposed in the literature for qualitatively define deterioration of cement based materials under sulphate attack. A brief literature review about these visual ratings has been made and a fuzzy theory based analysis has been conducted to investigate if increasing the number of visual rating categories improves the effectiveness in the appreciation of sulphate attack and how many categories in a visual rating would deem to be optimum. Uncertain nature of factors influencing the outcome of a visual examination is discussed.

Keywords: Fuzzy Logic, Sulphate Attack, Visual Rating, Classes

1.0 INTRODUCTION

Sulfate attack constitutes a major risk of chemical aggression for concrete and other building materials [1]. It is reported that sulphate attack is difficult to measure because it is the result of a complex set of chemical processes and there is still a lot of controversy about the mechanism of such attack [2]. Numerous laboratory tests have been developed to test such materials under sulphate conditions under accelerated conditions [3]. While these accelerated tests help to give due indication of the likely performance of such materials in field conditions, these methods are criticized on many counts. They are perceived to change the attack mechanism and make it differ from the one which exists in the field under
consideration [3]. Sometimes, laboratory tests may not simulate the conditions in the field. For example, a constant $p^H$ test may not correctly model stagnant sulphate solution though it may be useful for modeling flowing water conditions [4]. Still, these short-term accelerated tests are considered a necessity due to their time-advantages.

Visual examination of specimens is very important in such tests and has been done in many field conditions also [4-15]. Visual rating of effects is given in order to detect and classify damages occurring in the laboratory specimens & field concrete [16]. It has been reported that there is no standard criterion for evaluating the resistance of concrete exposed to chemical acidic environments [17]. One such rating given for thaumasite formation considers the depth to which thaumasite sulphate attack has occurred in the field conditions [18]. Progress of deterioration in terms of visual rating of mortar specimens has been given in a study [19]. Deterioration ratings for plain and blended cement mortar specimens exposed to 2%, 2.5% and 4% sulfate solution was provided in another study [20]. After the designated sulfate exposure period in a study, the deterioration was classified on a six-point scale ranging from 0 to 5. A rate of 0 indicated no deterioration while a rate of 5 indicated complete failure [6].

In a study, the visual examination of the samples was performed at regular intervals and all significant modifications, such as changes in surface color and texture, formation of coatings, deterioration, expansion and cracking were recorded. A ten point grading of various stages of damage [21] for limestone cement mortars was given, as shown in Table 1. In another study [22], three modes of deterioration of plain and blended cement concrete have been defined based on certain effects. These are given in Table 2. It has been suggested that for practical purposes, there is a need to relate the degree of severity of field exposure to the extent of the attack on concrete [9,23]. Four classes of exposure and three classes of severity have been recognized in some codes [24]. The importance of these may be appreciated as in a study it was reported that no data existed on the groundwater aggressiveness during the early life of the concrete elements. Consequently it was not known to what extent the attack was due to sulfuric acid, neutral sulfates or some combination of the two [8]. Damage levels in samples exposed to a $\text{Na}_2\text{SO}_4$ solution with 10,000 ppm sulfate ion concentration were qualitatively rated from 0 (no damage) to 4 (extreme damage) based upon visual examination [24]. Yet another study has proposed the visual rating for cement with limestone fillers, which is provided in Table 3 [12].

Three damage indices related to relative mass loss ratio, compressive strength variation, and elastic modulus variation are defined in a study [13]. Another study provides a rating, based on visual examination of concrete structures in the field, which is given in Table 4 [25]. Both of visual ratings A and D have been marked as severe but differentiated based on whether Alkali-silica reaction (ASR) was noticed. In rating A it was to be absent while it was present for rating D. Visual ratings given in Table 4 may be compared to those given in Table 5 for concrete, based on another study [26]. In Table 4, a holistic view seems to have been taken while a focused view of features of various types of effects is seen in Table 5. A rigid correspondence between the two may not be there even if the rating were proposed in the same study because of likely variations at different locations.

Apart from these ratings, site classification, sulphate classes and aggregate chemical environment classes have been proposed based on certain correlations [23]. Although there is a general agreement between the trends of results exhibited by chemical and micro-biological tests in comparing the resistance of different concretes to sulfuric acid attack, some discrepancies can occur [27]. It is suggested that the visual examination is more applicable in
comparing the relative performances of different concrete mixtures [2]. Another rating, which was used in a study [17] of performance of self-compacting concrete in acidic environment is given in Table 6. Though this rating system tries to differentiate various stages, it seems very difficult to actually differentiate in border line cases.

Table 1: For limestone cement mortars

<table>
<thead>
<tr>
<th>Visual rating</th>
<th>Recorded effects from visual examination</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No visible deterioration</td>
</tr>
<tr>
<td>1</td>
<td>Some deterioration at corners</td>
</tr>
<tr>
<td>2</td>
<td>Deterioration at corners</td>
</tr>
<tr>
<td>3</td>
<td>Deterioration at corners and some cracking along the edges</td>
</tr>
<tr>
<td>4</td>
<td>Deterioration at corners and cracking along the edges</td>
</tr>
<tr>
<td>5</td>
<td>Cracking and expansion</td>
</tr>
<tr>
<td>6</td>
<td>Bulging of surfaces</td>
</tr>
<tr>
<td>7</td>
<td>Extensive cracking and expansion</td>
</tr>
<tr>
<td>8</td>
<td>Extensive spalling</td>
</tr>
<tr>
<td>9</td>
<td>Complete damage</td>
</tr>
</tbody>
</table>

Table 2: For plain and blended cements

<table>
<thead>
<tr>
<th>Mode of deterioration</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode 1</td>
<td>Eating away of the hydrated cement paste and progressively reducing it to cohesionless granular mass leaving the aggregates exposed – reduction of cross sectional area – decrease in strength</td>
</tr>
<tr>
<td>Mode 2</td>
<td>Expansion and cracking</td>
</tr>
<tr>
<td>Mode 3</td>
<td>Onion peeling type of scaling or shelling of the surface in successive layers in the form of delamination</td>
</tr>
</tbody>
</table>

Table 3: For cement with limestone fillers

<table>
<thead>
<tr>
<th>Visual rating</th>
<th>Recorded effects from visual examination</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No visible deterioration</td>
</tr>
<tr>
<td>1</td>
<td>Deterioration at corners and edges</td>
</tr>
<tr>
<td>2</td>
<td>Cracking along the edges</td>
</tr>
<tr>
<td>3</td>
<td>Extensive cracking and expansion</td>
</tr>
<tr>
<td>4</td>
<td>Spalling and disintegration of surfaces</td>
</tr>
</tbody>
</table>

Table 4: For concrete structures in the field

<table>
<thead>
<tr>
<th>Visual rating</th>
<th>Recorded effects from visual examination</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Severe</td>
</tr>
<tr>
<td>B</td>
<td>Moderate</td>
</tr>
<tr>
<td>C</td>
<td>None</td>
</tr>
<tr>
<td>D</td>
<td>Severe</td>
</tr>
</tbody>
</table>
Table 5: For concrete

<table>
<thead>
<tr>
<th>Visual rating</th>
<th>Recorded effects from visual examination</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No visible changes</td>
</tr>
<tr>
<td>1</td>
<td>Appearance of first visible cracks</td>
</tr>
<tr>
<td>2</td>
<td>Numerous cracks on the sample</td>
</tr>
<tr>
<td>3</td>
<td>Totally disintegrated sample</td>
</tr>
</tbody>
</table>

Table 6: For self-compacting concrete in acidic environment

<table>
<thead>
<tr>
<th>Visual rating</th>
<th>Recorded effects from visual examination</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No attack</td>
</tr>
<tr>
<td>1</td>
<td>Very slight attack</td>
</tr>
<tr>
<td>2</td>
<td>Slight attack</td>
</tr>
<tr>
<td>3</td>
<td>Moderate attack</td>
</tr>
<tr>
<td>4</td>
<td>Severe attack</td>
</tr>
<tr>
<td>5</td>
<td>Very severe attack</td>
</tr>
<tr>
<td>6</td>
<td>Partial disintegration</td>
</tr>
</tbody>
</table>

A Performance grading in terms of equivalent damaged depths has been provided in a study [28]. Likewise, another study has provided a visual rating of deterioration based on area of aggregate surface exposed with time and volume of specimen remaining intact [29]. An index, called ‘Wear rating’, is specified in another study to provide a quantitative measure of attack. It is defined as the average depth of erosion or damage for one corner (in mm) [30]. Wear rating has been found to be a useful quantitative indicator of the degree of conventional sulfate attack, but is unfortunately relatively insensitive for assessing thaumasite sulphate attack, where erosion occurs evenly across the face and is not concentrated on corners [30,31]. In some other studies, upper limits of certain effects have been proposed to give an indication of the failure stage of specimens. A 0.02% expansion limit to classify failure of specimens exposed to a 1% solution of sodium sulfate has been reported [2]. A visual rating scale for evaluation of concrete based on a scale of 1.0–6.0 has been given, with the upper limits indicating failure [2]. Similarly, a drop of more than 25% strength also has been reported to indicate failure [2].

2.0 FUZZINESS OF VISUAL RATINGS

Fuzzy set theory was developed by Lotfi Zadeh in 1965 to deal with the imprecision and uncertainty often present in real-world applications. It was subsequently further developed by Mamdani and several other researchers. Fuzzy system is a logical system, an extension of multi-valued logic, which is synonymous with the theory of fuzzy sets. The theory of fuzzy sets relates to the classes of objects with unsharp boundaries in which membership is a matter of degree. Similar types of conditions exist in the case of field visual examination of deterioration effects and in the interpretation of field conditions such as sulphate exposure etc. It has been emphasised that development of predictive models, combined with rapid index tests and making use of relevant performance databases may provide useful solutions eventually because testing for all possible exposures would be both cost and time prohibitive [4]. Importance of application of Fuzzy Logic system along with in interpreting results of laboratory visual examination in field conditions has been emphasized, in view of uncertainties of effects, varying conditions of tests in laboratory and in the field and nomenclature of visual effects [32].
Though visual examination is an important tool for the assessment of the effects of an aggressive environment on cement based materials & for interpreting the visual effects seen in the field, the findings of the examination may not be treated as fully conclusive & final in view of many uncertainties. Though theoretically the use of visual ratings to assess the conditions and performance of materials should be an easy task, it is not so due to variations of conditions in respect of material composition & characteristics, site, exposure and other related aspects. Numerous combinations and time variations of these factors in these combinations indicates the need of a consideration of conditions and effects from a fuzzy point of view. Some of these aspects are discussed below.

2.1 Aspect 1

It has been reported that there is no universally accepted criterion for measuring failure of laboratory specimens exposed to sulfate [2]. Importance of longer term exposure is found necessary to obtain more realistic indications of durability for extended service life [33]. Visual examination of specimen kept in an aggressive medium, such as a sulphate solution, gives many clues about the state of the material and level of deterioration in it at a particular stage of the test. Various stages of degradation may be represented by different effects which are seen in various forms. Appearance of fine cracks on the surface [19], formation of subsurface cracks [24], spalling of surface material [6,34,35], crazing [20], blistering of surface [34,36], expansion in length [34], loosening of material [35], corner cracking combined with transverse surface cracks [6], swelling of corners [37], a complete breakdown of samples [19], appearance of soft pulpy mass of mortar [4,19], debonding of matrix from aggregate particles [35], extreme distress [6], onion peeling type degradation of samples [38], change in colour [35], erosion of faces [34,36], softening of external layer of mortar specimen [19], loss of cohesion of mortar [7], formation of gypsum crystals [35,36,39], formation of efflorescence on the surface [35,36] and formation of mushy layer on the surface [40] are some of the effects which have been visually noted and interpreted. Many visual rating classifications use a particular effect to denote a particular stage of deterioration in cement based materials. It has to be appreciated that many of such effects are normally simultaneously present and visual rating classifications are not clear as to what rating of deterioration should be allotted in such cases. Under such conditions, the presence of a particular effect is a matter of degree and it calls for a fuzzy decision making.

2.2 Aspect 2

Difficulties related with assessment of deterioration are not completely wiped out even if some other indicators are used with visual identification of effects. Many quantitative indicators such as mass loss, expansion and compressive strength reduction have been used as indicators for evaluating the resistance of concrete to sulfuric acid attack [1,3,5,6,19,21,27,41,42]. A difficulty in the development of visual ratings and associated effects in measurable properties is that none of the indicators, giving information about the condition of material at a stage, is considered ideal [3]. Loss of mass has been indicated as the best indicator for the assessment of sulphate attack [3]. But in another study, expansion and compressive strength reduction were found to be the most reliable measures to indicate the sulphate attack while loss of mass found to be negligible and insignificant [6]. It has also been reported that even a small procedure such as brushing or no-brushing before regular weighting of specimens, exposed to sulfuric acid, has influence on results obtained and related conclusions [27]. Any relationship between mass loss and compressive strength loss
should be taken cautiously since the two manifestations are governed by different factors and are not directly related [27]. The most of available literature on the resistance of concrete to sulfuric acid attack has not discussed the correlation between mass loss and strength loss and consequently, this relationship remains questionable [27]. But, many times, visual observations are found to be in good agreement with the results obtained by quantitative methods [34,38,39]. Without doubting the importance of visual examination in the assessment of sulphate attack, it has been reported that sole visual inspection can be misleading in some situations [43]. Therefore, a need of more rigorous methods to evaluate the performance of mortar / concrete, under sulfate attack, has been outlined [44]. Studies related with microscopic appearance and characteristics of crystals have been taken up with scanning electron microscopy, usually equipped with an energy dispersive X-ray spectrometer (SEM-EDS), procedure [5]. Use of optical measurements and stereomicroscopy has been reported to be the required first stage of visual examination [5]. Use of X-ray diffraction (XRD) has been suggested for the determination of deposits of calcite formed on the surfaces [42,45]. High-resolution X-ray computed tomography also has been used in a study of sulfate attack to make approximate sequence of increasing damage [24]. Petrographic examination of a concrete strip foundation of low cement content has been reported [46]. Measurement of fundamental transverse frequency and ultrasonic pulse velocity also has been reported [8,21,42]. Use of thermal analysis for getting the status of samples stored for a period of 5 years also has been reported [21]. Concrete samples have also been examined with scanning electronic microscope (SEM) for features of paste–aggregate interfacial zones and analysed with energy dispersive X-ray (EDX) micro-analyser for evidence of reaction products of acid attack [21]. Laser induced breakdown spectroscopy can also be used for the quantitative measurement of sulfur contents in building materials [1]. Use of Micro-X-ray fluorescence (XRF) for detailed analysis of the distribution of damaging sulfates has also been made [1]. Image analysis techniques also have been used for the determination of sulfate attack [44]. Microtomography of the interiors of samples also has been undertaken to rate the deterioration of samples [24]. Concrete deterioration and morphological changes in cement hydrates also have been studied to have a correlation between laboratory and field samples [47]. At the same time, it also has been reported that it is difficult to assess the degree of deterioration in sulphate attack in a quantitative manner [18].

2.3 Aspect 3

In laboratory experiments, the specimen is under a different condition of stress compared to field concrete. Required depth of penetration of aggressive solution into the specimen to make appreciable changes in strength parameters is less in laboratory experiments. Though this may not affect visual observations on the surface, both of the above-mentioned aspects as well as shape and size effects may affect the correlation between visual ratings ascribed to specimen in the laboratory and strength degradation in the field. Change in aspect ratio, variability of geometry across the height of specimens leading to planes of stress concentration, load eccentricity, consideration of effective cross-sectional area of the sound core instead of the initial cross-sectional area and non-uniform stress distribution during compression testing may have a pronounced effect on the reliability of the determined compressive strength [27]. Increase in volume/surface ratio of specimens has been reported to cause a corresponding increase in initiation time of degradation of paste, mortar and concrete specimens [28]. In a study, the initiation of cracking and failure of the
samples was found to depend significantly on their thickness and a need of consideration of scale effects has been felt [19]. Changes of some of visual parameters may not give a true idea of changes in properties of mortar / concrete, especially in the initial stage of the test. A surface colour change or a peeling of some material from the surface of the specimen may not definitely mean a necessary change in strength of material. It has been reported that sometimes cement paste may be at an advanced stage of sulphate attack but the strength drop may not be observed in the samples [3]. This may be true in the case of field concrete where the inside of concrete is in a confined condition. Further, it is very complex to compare data obtained from different studies [12].

2.4 Aspect 4

Existence of varying conditions with respect to the cation type in sulphate, presence of binders & fillers and quality of concrete may also present fuzzy effects. Performance of cement mortar and concrete depends on the cation of the sulphate salts to an appreciable extent. MgSO\(_4\) has been reported to have more damaging effect than Na\(_2\)SO\(_4\) for certain mixes [5,41,34,48,49]. The opposite of this also has been reported [37,50]. While pozzolanic admixtures tend to significantly reduce expansion due to sulfate exposure, it was reported in a study that such a beneficial effect was not achieved with regards to MgSO\(_4\) surface degradation [41,23,49,52-53]. Another difficulty based on general information is that cement paste, mortar and concrete behave differently to the same nature of sulphate attack [3,54-60]. A possible interaction between the quality of concrete and the w/c ratio of the mix has been taken to be a further complication [9]. While comparing laboratory and field results, the inability of varying only one parameter at a time presents difficulties. This happens, for example, in case of variation in case of w/c ratio which results in variations in compressive strength and density as well.

2.5 Aspect 5

In recording the results of visual examination, another difficulty comes from the point of view of nomenclature of viewed effects. Words such as ‘severe distress’ may connote different meanings without giving a clear interpretation of structural effects seen in samples. Sometimes, visual effects of two different stages may be inadvertently combined [34,28]. For example, deposition of white material such as gypsum and severe cracking may be reported in combination while the former might have taken place much before the latter one. For it, initiation and further development of a particular effect should be continuously monitored and different stages of various effects at a particular time should be considered. Details of studies, undertaken in the past, would be important in the observation phase [61-64].

3.0 DETAILS OF STUDY

If visual ratings given in Table 1 to 6 are considered, it may be appreciated that these ratings classify a deterioration stage on the basis of a particular effect, such as appearance of crack etc. For the next stage, any other effect may be considered. As the effects seen in previous stages are not concealed when the next stages come, confusions may occur in deciding the deterioration stage at a particular time. Due to this reason, increasing the total number of visual rating classes (such as 10 in Table 1) may not practically help in effectively grading the deterioration. Broadly defining various stages of attack as ‘very slight’, ‘slight’
and ‘moderate’, as shown in Table 6, also may not help as the boundaries between adjoining rating classes still remain fuzzy.

In this study, based on fuzzy logic, an effort has been made to determine if confidence in results of visual examination, supported by tests, improve by increasing the number of classes in a visual rating system. Fuzzy modeling of some of the visual rating systems given in Table 1 to 6 is done. Two fuzzy inputs are considered in the study. The first one consists of many classes depending on the visual rating system being considered in the form of triangular membership function. It considers the fuzziness among various classes of deterioration. The membership function of the second input, which considers supplementary information about site and exposure, has been denoted in the form of trapezoidal functions defining three categories of confidence marked as Poor, average and good. It has been appreciated that deterioration of concrete in the field may not be defined properly unless visual observations are supported by associated information about sulphate exposure site class, quality of concrete, age, other material & structural parameters etc. Member functions of the second input is assumed to consider all these parameters. Fuzzy inference rules made in this study accept a proportional relationship between the confidence in input 2 and the output confidence. The output confidence is taken in terms of a gauss membership function. The defuzzification module considers centre of maxima method to provide confidence of results of visual examination. The fuzzy logic system, used in the study is shown in Figure 1.

Figure 1: Fuzzy system

Only input 1, out of three cases taken in this study, is subject to variation. As input 1 considers the total number of rating categories in a visual rating classification, it has been considered to contain 3, 5 and 9 membership functions. The definition of membership functions for input 2 remain the same for all the cases. Membership functions for all the three cases of input 1 are shown in Figure 2. Output confidence for low-low, low-high, high-low and high-high values of input 1-input 2 values have been determined. Figure 3 shows ruleview for a test case when the values of confidence in input 1 and input 2 are varied systematically. One of the Fuzzy inference systems, used in this study, is given below.

[System]
Name=visual 9' 
Type='mamdani'
Version=2.0
NumInputs=2
NumOutputs=1
NumRules=27
AndMethod='min'
OrMethod='max'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='centroid'

[Input1]
Name='recorded_effect'
Range=[0 1]
NumMFs=9
MF1='stage1':'trimf',[-0.0128 0 0.128]
MF2='2':'trimf',[0.0726 0.15 0.22]
MF3='3':'trimf',[0.165 0.25 0.321]
MF4='4':'trimf',[0.274 0.366 0.427]
MF5='5':'trimf',[0.375 0.468 0.53]
MF6='6':'trimf',[0.485 0.568 0.63]
MF7='7':'trimf',[0.579 0.662 0.729]
MF8='8':'trimf',[0.682 0.767 0.833]
MF9='9':'trimf',[0.78 1 1.22]

[Input2]
Name='input_accuracy'
Range=[0 1]
NumMFs=3
MF1='poor':'trapmf',[-0.45 -0.05 0.05 0.308]
MF2='average':'trapmf',[0.207 0.45 0.55 0.78]
MF3='good':'trapmf',[0.686 0.95 1.05 1.45]

[Output1]
Name='output_confidence'
Range=[0 1]
NumMFs=3
MF1='poor':'gaussmf',[0.2123 0]
MF2='average':'gaussmf',[0.2123 0.5]
MF3='good':'gaussmf',[0.2123 1]

[Rules]
1 1, 1 (1) : 1 1 2, 2 (1) : 1 1 3, 3 (1) : 1 2 1, 1 (1) : 1 2 2, 2 (1) : 1 2 3, 3 (1) : 1 3 1, 1 (1) : 1 3 2, 2 (1) : 1 3 3, 3 (1) : 1 4 1, 1 (1) : 1 4 2, 2 (1) : 1 4 3, 3 (1) : 1 5 1, 1 (1) : 1 5 2, 2 (1) : 1 5 3, 3 (1) : 1 6 1, 1 (1) : 1 6 2, 2 (1) : 1 6 3, 3 (1) : 1 7 1, 1 (1) : 1 7 2, 2 (1) : 1 7 3, 3 (1) : 1 8 1, 1 (1) : 1 8 2, 2 (1) : 1 8 3, 3 (1) : 1 9 1, 1 (1) : 1 9 2, 2 (1) : 1 9 3, 3 (1) : 1
Figure 2: Membership functions
Figure 3: Ruleview for particular values of input and output

Surface view for input and output is shown in Figure 4.

Figure 4: Surface view
4.0 DISCUSSION

It can be seen from the rule view and surface view that the output confidence depends, to a great extent, on the confidence on input variable 2. It depends on the availability of information with respect to site, material, environmental and exposure conditions. Nature of these variations has been found to be of the same type in all the three cases. It is observed that value of input 2 affects the output confidence to a greater extent than input 1. A systematic change of input 1 and input 2 has been shown in Table 7 and output confidence values are noted.

Table 7: Output with variations in input values

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Rating system with 3 classes</th>
<th>Rating system with 5 classes</th>
<th>Rating system with 9 classes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Input 1</td>
<td>Input 2</td>
<td>Output</td>
</tr>
<tr>
<td>1</td>
<td>0.509</td>
<td>0.500</td>
<td>0.500</td>
</tr>
<tr>
<td>2</td>
<td>0.018</td>
<td>0.500</td>
<td>0.500</td>
</tr>
<tr>
<td>3</td>
<td>0.978</td>
<td>0.500</td>
<td>0.500</td>
</tr>
<tr>
<td>4</td>
<td>0.509</td>
<td>0.026</td>
<td>0.167</td>
</tr>
<tr>
<td>5</td>
<td>0.509</td>
<td>0.987</td>
<td>0.834</td>
</tr>
</tbody>
</table>

Following points may be noted from the data given in Table 7.
- As shown in row marked as S.N. 1, for the medium confidence, shown with a value close to 0.5, in both input 1 and input 2, the output confidence is medium.
- In row S.N. 2, value of input 1 has been taken to be very low while input 2 remains as such. Value of output confidence does not change in all the cases.
- In row S.N. 3, value of input 1 has been taken to be high while input 2 remains as such. Value of output confidence does not change in all the cases.
- In row S.N. 4, value of input 1 has been restored as its initial value while input 2 has been assigned a low value. Value of output confidence lowers down tremendously in all the cases.
- In row S.N. 5, value of input 1 has been taken as its initial value while input 2 has been assigned a high value. Value of output confidence shoots up in all the cases.

The above facts deduced from Table 8 clearly indicate that the output confidence in the results of visual examination in laboratory and field studies depends more on the confidence generated due to the availability of accurate information rather than number of classes in a visual rating system, being used.

If a visual rating classification system consists of too many classes, boundaries between adjoining classes become more and more fuzzy and it may be difficult to accurately select the right deterioration stage for the material. If the number of classes is too low, then also the reach of the classes becomes very broad and the meaning of a particular class becomes vague. Continuing with the point, if only two stages are there in a visual rating classification system then deterioration may be given either as ‘nil’ or ‘full’. Theoretically, only 50% accuracy may be probable in determining the value of input 1 in such a case. This may be understood if the concepts of ‘forced uncertainty’ and ‘opted uncertainty’, used in analysis of fuzzy systems is considered [65]. Forced uncertainty is a result of having too many classes
which may force us to the side of information deficiency. For example, if a class, in a rating system having too many classes, is dependent on the existence of a crack, even presence of very minute cracks which may not be observed with the help of available instruments may not help us to designate the appropriate deterioration rating corresponding to that class. If number of classes is reduced merging classes in the rating system, it becomes a case of ‘opted uncertainty’. This is not a result of any information deficiency but results from a lack of need for higher certainty. It is obtained by quantizing a variable beyond the coarseness induced by the measuring instrument involved. This additional quantization allows us to reduce information regarding the variable to a level desirable for a given task. While forced uncertainty is a subject of epistemology, opted uncertainty has been described to be of a pragmatic nature [65].

Based on visual ratings given from Table 1 to 6, considering that if the initial and final ratings in all of them are corresponding to no damage and full damage respectively, some common effects given in these tables at various stages may be combined, as given in Table 8. Some of the effects given at different levels in various rating systems may have to be joined to give an indication of the actual effect. It is proposed that any stage in a visual rating system should include all such effects to aid in giving a rating to the deterioration in cement based materials. The boundaries of the categories still remain fuzzy and these overlap one another by some degree.

Table 8 : Suggested effects in similar stages

<table>
<thead>
<tr>
<th>Stage</th>
<th>Possible effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No visible deterioration, white material deposition, some visible cracks</td>
</tr>
<tr>
<td>2</td>
<td>Expansion and cracking, some spalling at edges and corners, surface peeling off, partial disintegration</td>
</tr>
<tr>
<td>3</td>
<td>Mass loss (3-5%), partial disintegration, surface peeling off, extensive softening and spalling</td>
</tr>
<tr>
<td>4</td>
<td>Mass loss (about 10%), extensive softening and spalling, reduction of cross section, considerable disintegration</td>
</tr>
</tbody>
</table>

5.0 CONCLUSION

Following conclusions may be drawn from this study.

1. A visual rating system should contain an appropriate number of classes. This number should be neither too large nor too small. A classification with optimum number of rating categories has been proposed. It is appreciated that use of fuzzy logic can be effectively made in such situations.

2. Every class in a visual rating should be well defined in terms of all possible effects which may be present for a particular class of deterioration.

3. Visual examination for determining the extent of deterioration in the laboratory and field should be supported by other tests. It has been shown in this study that accuracy of these supporting tests is crucial in having a greater confidence in the outcome of results.

4. An expert system, using fuzzy logic and artificial neural network techniques, should be the natural outcome for more accurate determination of deterioration of cement based materials in the field.
REFERENCES

66. S.G. Umashankar and Dr.G. Kalivarathan, “Prediction Of Transportation Specialized Views of Median Safety by using Fuzzy Logic Approach” International Journal of Civil Engineering & Technology (IJCET), Volume 4, Issue 1, 2013, pp. 38 - 44, ISSN Print: 0976 – 6308, ISSN Online: 0976 – 6316, Published by IAEME.