PROPERTIES OF MALAYSIAN FIRED CLAY BRICKS AND THEIR EVALUATION WITH INTERNATIONAL MASONRY SPECIFICATIONS – A CASE STUDY

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This thesis is dedicated to the people very dear to my heart:

my late parents, Arman Ali Hj Mohibullah and Zabedah Hamzah

my husband, *Ayob Sharif*

and my children…
Amlina, Aliza, Alira, Afandi Akmal, Alia Atika and Arfa Adlina

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ABSTRACT

The research examined and assessed the properties of Malaysian fired clay bricks to provide information for the development and revision of Malaysian Standard MS 76:1972. Some laboratory investigations on bricks were conducted in conjunction with the use of various masonry standards to evaluate the compressive strength, dimensional tolerances, water absorption, initial rate of suction, efflorescence, density and soluble salt content. The test methods were mostly based on MS 76:1972 and BS 3921:1985 and in some cases new testing approaches were adopted to assess new property requirements not catered in existing masonry specifications. The analysis on random samples indicated the acceptance of the use of a normal probability theory even for data with values of coefficient of variation close to 30%. In the case where the coefficient of variation exceeded 30 % the log-normal probability function applies. The statistical control charts traced data homogeneity for the population and data lying beyond the 5 % confidence limit, which were not accounted for in the analysis. The compressive strengths of facing bricks ranged from about 40 N/mm^2 to 50 N/mm^2 with lower values for common bricks, i.e. 30 N/mm^2 to 40 N/mm^2. These ranges of compressive strengths fall in the top range specified in Singapore Standard, SS 103:1974. The compressive strengths specified in ASTM were based on dry curing whilst British Standard, Singapore Standard and Malaysian Standard were tested in saturated conditions. Curing methods affect compressive strength with air curing giving higher values. Water absorption for the bricks under investigation range from 10 % to 12 % and therefore do not fit in the category of Engineering A or B of MS 76:1972 and BS 3921:1985, however satisfy the requirements for the categories of SW (severe weathering) bricks in ASTM. The dimensions satisfy the tolerances given in BS 3921:1985 except for the height. However, the dimensional tolerance fits the T1 category of the European Standard EN 771-1. The initial rate of suction for the bricks ranged from 1.4 to 2.0 kg/min/m^2 indicating high suction property thus implying the necessity of wetting bricks before laying. Efflorescence does not seem to be a major problem hence these bricks could be satisfactorily used for facing construction purposes without resulting in salt deposition on the surfaces. The range of density (1760 to 1800 kg/m^3) exhibited by the bricks satisfy the sound insulation requirements specified in the United Kingdom Building Regulations. In this research a method of predicting the compressive strength of bricks when laid in the different orientations was derived. This is a useful means of estimating the compressive strength of brick in practice where test are only conducted on the bed face. The research also highlighted a method of estimating the porosity of bricks for values of known water absorption.

ABSTRAK

Penyelidikan ini mengkaji dan menilai sifat-sifat kejuruteraan bata tanah liat bakar negara bagi membekalkan maklumat yang diperlukan untuk pembangunan Standard Malaysia MS 76:1972. Beberapa ujian makmal ke atas bata telah dijalankan selaras dengan penggunaan beberapa standard masonry untuk menganalisis kekuatan mampatan, toleransi pendimensian, penyerapan air, kadar resapan awal, ketumpatan, kesan peroi dan kandungan garam larut. Sebahagian besar ujian-ujian ini adalah berdasarkan kaedah MS 76:1972 dan BS 3921:1985 manakala pendekatan ujian semasa juga digunakan bagi menganalisis ciri-ciri baru yang tidak terkandung dalam spesifikasi sedia ada. Analisis sampel yang dipilih secara rawak menunjukkan penerimaan penggunaan teori kebarangkalian normal walaupun untuk data di mana nilai pekali perubahan menghampiri 30 %. Bagi kes dimana nilai pekali perubahan melebihi 30 %, fungsi kebarangkalian log-normal digunakan. Carta kawalan statistik digunakan untuk mengesan kehomogenan data dan data melampaui 5 % had keyakinan yang tidak diambil kira di dalam analisis. Kekuatan mampatan bata permukaan adalah antara 40 hingga 50 N/mm^2 manakala bata biasa mempunyai nilai lebih rendah iaitu 30 hingga 40 N/mm^2. Julat kekuatan mampatan ini tergulung dalam kategori tertinggi Standard Singapura, SS 103: 1974. Kekuatan mampatan dalam spesifikasi ASTM adalah berdasarkan bata diawet udara. Berbeza dengan Standard British, Singapura dan Malaysia, di mana bata di uji dalam keadaan tepu. Pengawetan udara memberikan nilai yang lebih tinggi. Penyerapan air adalah antara 10 hingga 12 %. Nilai ini tidak menepati keperluan MS 76:1972 dan BS 3921:1985 untuk kategori bata kejuruteraan A dan B. Walau bagaimanapun ia memenuhi syarat yang ditentukan dalam spesifikasi ASTM bagi bata jenis SW (terdedah pada kesan cuaca yang teruk). Dimensi bata dapat memenuhi keperluan toleransi pendimensian bagi standard BS 3921: 1985, kecuali ketinggiannya. Di bandingkan dengan Standard Eropah EN 771-1 pula, didapati ia menepati kategori T1. Kadar resapan awal bata ialah dari 1.4 hingga 2.0 $kg/min/m^2$, menunjukkan ciri resapan yang tinggi, oleh itu bata perlu dibasahkan sebelum diikat. Bata tidak menghadapi masalah peroi, jadi ia boleh digunakan sebagai bata permukaan tanpa berlaku pemendapan garam di permukaannya. Julat ketumpatan bata ialah 1760 hingga 1800 kg/m^3, sesuai bagi penggunaan dinding bangunan dengan nilai rintangan kebisingan memenuhi spesifikasi kanun bangunan di United Kingdom. Dalam penyelidikan ini kaedah untuk meramalkan kekuatan mampatan bata apabila disusun dengan orientasi yang berlainan telah dapat dihasilkan. Kaedah ini berguna bagi menganggarkan kekuatan mampatan bata secara praktikal dimana ujian mampatan hanya dilakukankan di permukaan atas bata. Kajian ini juga menerangkan kaedah menganggarkan keliangan bata daripada nilai penyerapan airnya.

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LIST OF SYMBOLS AND ABBREVIATIONS

ANOVA	-	analysis of variance
Mpa	-	Megapascals
AS	-	Australian Standard
ASTM	-	American Standard of Testing Materials
BS	-	British Standard
c.v.	-	Coefficient of variation
df	-	Degree of Freedom
EN	-	European standard
MS	-	Malaysian Standard
MS	-	Mean of Squares
n	-	Sample size
N.H.	-	Null Hypothesis
NZS	-	New Zealand Standard
R	-	Range
s	-	Sample standard deviation
SS	-	Sum of squares
Std. dev.	-	Standard deviation
Var	-	Variance
ν	-	Coefficient of variation
$\overline{\overline{x}}$	-	Mean of sample means
μ	-	Population mean
σ	-	Population standard deviation
s^2	-	Sample variance
$\overline{x}$	-	Sample mean

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CHAPTER 1

INTRODUCTION

1.1 History and Development of Masonry

The history of civilisation is synonymous to the history of masonry. Man's first civilisation, which started about 6000 years ago, was evident by the remains of the Mesopotamians masonry heritage. During those days masonry buildings were constructed from any available material at hand. The Mesopotamians used bricks, made from alluvial deposits of the nearby River Euphrates and Tigris to build their cities beside these two rivers. Where civilisation existed in the vicinity of mountains or rocky outcrops, stone was used. The Egyptians pyramids that existed along the rocky borders of the Nile valley were examples of such stone masonry. In the Eastern civilisation remains of historical masonry is the reputed Great Wall of China, which is considered as one of the seven construction wonders in the world. The materials used in the construction varied from tamped earth between timbers and adobe i.e. sun-dried bricks to local stones and kiln-fired bricks. The part of the wall that remains until today is mainly those made of bricks and granite.

The early forms of masonry application in Malaysia dated back about 350 years ago with the construction of the Stadthuys in Malacca, built by the Dutch in 1650. A more modern form of masonry construction was initiated by the British who colonised the then Malayan Peninsula. Brickwork buildings were at that time built specially for government offices, quarters and residential. The administrative block,

Sultan Abdul Samad building built in 1894 and given a face-lift during the Fourth Malaysian Plan (1981 – 1985) is an example of a masonry heritage, which stands as a remarkable landmark of Kuala Lumpur.

In its early forms masonry structures were built without any structural calculations. Units of masonry consisting of stones or bricks were either stacked dry or bonded with any adhesive material to form structures and self weight being used to stabilise the construction. The Great Wall of China for example, stood at 6.5 meters wide at the base and 5.8 meters at the top, constructed at this massive scale mainly for stability.

With the advancement of engineering technologies and manufacturing the development of masonry units and their applications have extended beyond the conventional approaches and processes leading to a more efficient design and economy. Situations where considerable lateral forces have to be resisted, the low tensile strength of bricks could be overcome by using reinforced masonry. Construction where greater span lengths is desired, post tensioned bricks are used, making it possible for bricks to be used in large single cell buildings.

1.2 Manufacturing of Clay Bricks

Clay brick is the most extensively used type of masonry units throughout the world. Its widespread use is mainly due to the availability of clay and shale in most countries. Its durability and aesthetics appeal also contribute to its extensive application in both load bearing and non-load bearing structures.

Manufacturing techniques for the production of clay bricks have changed from the initially hand moulded processes to modern mechanisation. At present bricks are formed either by the process of extrusion, moulding or dry pressing. These advance techniques of manufacturing allow greater flexibility in its design; with a more efficient and varied burning process a wide range of products can be manufactured. Longer burning processes also tend to produce denser units thus

allowing its use for load bearing purposes. Other variations including appearance, colours, textures, sizes and physical properties could be designed accordingly to the type of bricks to be produced and its application.

1.3 Construction Requirements for Masonry and the Needs for Specification

Due to the varying manufacturing process and the raw materials, bricks produced could have a wide range of variability in its appearance and physical properties making brick a versatile building unit in construction. Bricks are of great importance for load bearing walls in low and medium rise buildings and for non-load bearing walls as cladding for buildings. It serves several functions including structure, fire protection, thermal and sound insulation, weather protection and subdivision of space.

The several functions of bricks and the availability of a variety of bricks that are able to serve the different construction requirements therefore require an efficient and consistent guideline in achieving a safe, efficient and economical design. This is often dictated by specifications and standards.

Load bearing brickworks, besides functioning as subdivision of space should also have the load carrying capacity, necessary thermal and acoustics insulation as well as fire and weather protection. Consequently, bricks in load bearing applications should have adequate strength so that it could safely carry the loads imposed by the structure and be able to meet the other physical requirements specified in standards. On the other hand, non-load bearing brickworks are non-structural, which are designed not to carry load and therefore consideration for strength is of less importance compared to the requirements needed in load-bearing masonry.

A damp-proof-course in brick walls at ground floor level prevent moisture from the ground rising through the bricks and mortar and causing dampness in the lower parts of the ground floor walls. For this reason bricks used as damp-proof-

course must be sufficiently impermeable and this could be ascertain through its water absorption property.

Facial bricks are mostly produced as quality bricks with high compressive strength and low water absorption as they can be efficiently applied as structural bricks with aesthetics quality for use in external walls. These bricks should also possess other physical requirements essential in good brickwork practices.

1.4 Masonry Standardisation and International Developments

The earliest standard was for weights and measures, which could be traced back to the ancient civilisation of Babylon and early Egypt (IEEE, 2001). However, the importance of standardisation was only fully realised until during the industrial revolution of early nineteenth century.

As for masonry, standards had evolved through research discoveries and the experience acquired over the years in the use of masonry. Each masonry standard is different and unique for any country as it incorporates the national requirements. As such the brick specifications for Australia, America, Britain differs. However, the basic approach may be similar, to some extent. These standards were developed more than several decades ago and used the prescriptive approach.

The trend towards globalisation requires harmonisation of standards and this is evident with the European Standard (EN), which was established to encourage trade between the European member states and the EN 771 became the new standard thus setting new specifications of masonry units for Europe.

1.5 Defining the Contents for Standard Specifications

The international masonry standards define specifications by consideration of the parameters described in the foregoing paragraph.

With respect to the mechanical properties of bricks, the most important is compressive strength, which as well as being direct importance to the strength of a wall, serves as a general index to the characteristics of the bricks. It is measured by a standardised test, the results rely to a certain degree on the standard procedures and conditions for testing prescribed in standards.

Bricks vary in their dimensions due to the variable shrinkage occurring during and after manufacturing. This dimensional variability should be a minimum in facing brickwork to ensure even joints for an aesthetically pleasant wall.

Water absorption of brick, which indicates bricks permeability, is dependent on its porosity. Porous bricks will allow water to penetrate a wall more easily thus contributing to problems of water seepage in masonry walls. This is an important factor to be considered in masonry materials especially for tropical regions where there is abundance of rain. In temperate countries, water absorption property of a brick is used in standards in defining bricks durability in terms of its resistance to freezing and thawing.

The initial rate of suction, which is the amount of water sucks by the brick from mortar during laying, affects the bond between bricks and mortar in a brickwork and is a required parameter in design of flexural walls. Optimum bond strength could be achieved by ensuring the initial rate of suction is within the specified limits in standards.

The other property, which is known to affect the appearance of a wall and therefore critical in facing bricks is the effects of efflorescence. The whitish salts deposits that appear on bricks surfaces are called efflorescence. Efflorescence is caused by the presence of soluble salt in the bricks and water as the carrier, which transport the salts to bricks surfaces.

The content of detrimental soluble salts in bricks also affects the durability of brickwork. For example, if the amount of water-soluble sulphate exceeds the allowable, sulphate attack will occur which will cause the disintegration of brickwork and thus affecting its durability.

The various standards adopt different methods of measurement for evaluating the properties of bricks. Limits may be specified to provide guidelines in achieving satisfactory results of the final construction.

The Malaysian standard MS 76:1972 was a mere adoption of BS 3921, excluding certain properties not relevant to Malaysian requirements, and therefore limiting to a number of main properties only. With the advent of highly technical manufacturing techniques and subsequently the presence of new range materials, materials may have to be tested for additional physical and chemical properties, to ensure its best performance after laid on construction site.

An improvement of Malaysian Standard is essential to cater with current technical requirements and ensuring effectiveness of masonry applications. This entailed investigations on brick properties before any recommendations could be made on the materials and limits set to achieve satisfactory results in construction.

The research examine the various masonry specifications including Malaysian Standard in an attempt to establish a better understanding of the various standards and in deriving recommendations for Malaysian applications relating to new technical requirements.

1.6 Research Problem

The development of the existing Malaysian standard MS 76:1972 (Specification for bricks and blocks of fired brickearth, clay or shale) were based on BS 3921:Part 2:1969 (Specification for Bricks and blocks of fired brick-earth, clay or shale). The British Standard had been revised twice, the latter versions being BS

3921:1974 and the existing BS 3921:1985. The revisions incorporate significant details pertaining to material requirements and construction practices. Some of the significant changes in existing British Standard BS 3921:1985 (British standard specification for clay bricks) include bricks classifications, designations for durability and new requirements on physical properties and revision of testing methods.

The shift of British standard to European standard and eventual withdrawal of the British Standard, therefore requires the Malaysian Standard to be revised accordingly to suit to current market products and requirements for masonry applications. Subsequently a research is necessary to study the various international masonry specifications in providing a detailed understanding of the specifications requirements, before recommendations be made to improve the existing brick specification for Malaysia. These efforts will also facilitate the development of a national standard capable of complying with standard global requirements.

In producing a national brick specification, data on local brick performance are required to guide and support the new set of recommendations proposed for the new standard.

The Malaysian Standard MS 76:1972 requires some essential amendments to its specification to cater for present masonry application. For example, the existing specification does not require any limit of salt content for ordinary quality facing and common bricks, which are meant for external applications. Limits of soluble salt content in bricks are essential as a preventive measures for salt deposition and detrimental chemical reaction, which could damage the appearance of facial brickwork construction. Investigation on the initial rate of suction property for Malaysian bricks is crucial as this property, which is at present not included in the specification, is an important criterion in structural brickwork design and calculations.

The supplementation of data relating to local bricks performance is essential to guide and support the new recommendations proposed for the improved standard mentioned above.

1.7 Aim and Objectives of the Research

The aim of the research is to establish a detailed understanding of brick properties through some laboratories investigations in conjunction with use of various masonry standards to assess the material performance. The results of these work supplemented with statistical studies and reviews of past research provides a useful guidance to brick properties for local production. These work will also provide data pertaining to current production of bricks which may be considered significant to any revision or amendment made to the existing Malaysian Standard for masonry MS 76:1972, currently under revision.

The objectives of the research are:

(i) To conduct an experimental investigation on compressive strength, dimensional tolerances, density, initial rate of suction, water absorption, efflorescence and soluble salt content of facing bricks.

(ii) To examine the compressive strength of common bricks.

(iii) To examine the compressive strengths of bricks tested in various orientations as recommended by Australian/New Zealand and European standard. Thus establish the relationship between the aspect ratio (h/t) and compressive strength of bricks.

(iv) To study the density of bricks and its relation to acoustics properties of masonry.

(v) To examine the statistics of locally manufactured bricks and the respective control charts representing the population of bricks under study.

(vi) To establish the relationship of water absorption, porosity and compressive strength of bricks and to predict compressive strength from known values of water absorption and porosity.

The studies were conducted through laboratory investigations of local bricks and literatures establishing the state-of-the art of previous works and references to international specification of masonry.

1.8 Scope of Work

The research is a case study, which dealt with the investigation of fired clay facing and common bricks from a local manufacturer. The bricks were tested under laboratory conditions as specified by the respective standards. The brick properties examined were confined to studies on compressive strength, dimensional tolerance, density, initial rate of suction, water absorption, efflorescence and soluble salt content. Majority of the tests were based on the Malaysian Standard MS 76:Part 2 1972, which is basically an adoption of British Standard, BS 3921:1969. Since then the British Standard for masonry has been revised several times to accommodate changes for current needs.

Other standards used in the study were ASTM (American society for testing and material), Australian/New Zealand standard, Singapore standard and European standard. These standards formed the major references for comparisons of the applications and methods of testing and determining the bricks properties investigated in this programme. They form the major references for discussions in this thesis.

Studies on bricks density are new to masonry and this was included in this research in aligning with the new recommendations specified by the European Standard.

The outcomes of the laboratory investigations were based on a local brick manufacturer and therefore the results are inconclusive to suggest a representation of the national population, however provides some guides to the properties of Malaysian clay bricks.

1.9 Layout of Thesis

Chapter II describes the significance of physical and chemical properties of bricks and its effects upon masonry behaviour. A review was conducted to examine the various international masonry specifications, the recommended methods of testing and measurements and comparisons between them. A considerable amount of attention was given to the studies on masonry specifications by Malaysian Standard, British Standard, and the Eurocode. Comparisons were also made by referring to Australian/New Zealand Standard and ASTM. The limitations and advantages of the various standards were highlighted and these form the basis of knowledge for the work carried out in this thesis and where possible recommended for future standard development.

Chapter III describes the laboratory works to identify the physical and chemical properties of local clay bricks in providing data for Malaysian bricks. The compressive strength, density, dimensions, water absorption, initial rate of suction, efflorescence and salt content were investigated mainly using British Standard and in specific cases other standards were also used. The British Standard is regarded as the main reference used in this research as it is used widely in practice in Malaysia.

Chapter IV presents the statistical analysis of bricks properties investigated in Chapter III. The descriptive statistics of data were computed and the graphical distribution of data shown by histograms and normal curves. The application of control charts was presented for testing data homogeneity. The analysis of variance, ANOVA was used to derive the components of variances in samples, which in turn will be used to calculate the bricks population mean.

Chapter V presents the experimental and statistical results for the bricks properties investigated in the programme. The results for every parameter were discussed and compared to previous research works and specification requirements set by existing international standards.

Chapter VI presents a method of predicting compressive strength and porosity properties of bricks based on the findings of work carried out in this thesis.

Chapter VII presents the conclusions of the works and recommendations for future studies.

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