THE FIRE PERFORMANCE OF LIMESTONE

Characterisation Strategy for the Fire Performance of Maltese & Hungarian Limestone

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Abstract

Limestone is exploited as dimensional building stones for construction. Fire and high temperatures cause significant changes in physical & mineralogical properties of limestone in buildings and historic monuments. A strategy to investigate limestone is developed with reference to different limestones in Malta and in Hungary. The changes in properties of the limestones are assessed with respect to different test conditions including homogenous heating and the standard fire curve. The startegy includes an assessment of the physical parameters (density, porosity, water absorption, UPV, uniaxial compressive strength and indirect tensile strength); petrographic analysis (polarising microscope, XRD, SEM); colour and durability anlysis. A preliminary investigation of specific properties of limestone exposed to high temperatures is presented.

Keywords: fire resistance, limestone fire performance

INTRODUCTION

Limestone is used in the construction industry in various applications including new structures and in restoration of historic stone monuments. Exposure to fire and high temperatures cause significant changes in the physical and mineralogical properties of limestone. The aim of this research is to propose a strategy to assess the fire and high temperature performance of limestone. The proposed strategy is supported with preliminary studies conducted in Malta and in Hungary to assess the fire and high temperature perforamnce of different limestones. Furthermore the aim of the research is to conduct a comparative analysis of the performance of Maltese and Hungarian limestones when exposed to fire and high temperature, within the framework of the strategy.

In the first phase of the investigation, two Maltese limestones and three Hungarian limestones are investigated. The material selected originates from different geological despoits and has varying properties including physical and mineraological characteristics. In the case of Malta, the first phase of the investigation refers to the main two varieties of limestone used in construction namely lower Globigerina limestone and Coralline limestone. The investigation is intended to lead to a first scientific understanding of the performance of Maltese limestones when exposed to fire. In the case of Hungary, the three limestones selected include Compact Limestone, Oolitic limestone and Travertine, with varying characteristics.

1 THE FIRE PERFORMANCE OF STONE BUILDINGS

The fire performance of stone buildings is important with respect to historic structures but also contemporary structures as in the case of Malta where stone is one of the main construction materials used also for loadbearing structures. Natural stone masonry can be seriously affected in building fires (Chakrabarti B., 1996). At high temperatures of 600 to 800°C, the strength of stone is reported to be seriously affected, and disintegration is reported in the case of thermal shock. Damage at lower temepratures of 200 to 300°C is normally restricted to colour changes, including reddening in the case of stone containing iron. Colour change is considered to be non-reversible and therefore damage can be significant (Chakrabarti B., 1996). The performance of stone from different sources when exposed to fire and high temperatures varies depending on the characteristics of the stone. Figure 1 refers to an Indsutrial Building in Malta, which was exposed to fire resulting in the collapse of the composite roof structure which included steel beams and reinforced prestressed hollow concrete elements. The loadbearing masonry walls are still standing but damage in stone masonry occured due to fire exposure but also failure as a conseuqnce of the collapse of roof elements.

Fig. 1 Damaged load-bearing masonry building in Malta exposed to fire

2 RESEARCH STRATEGY

The research strategy refers to the fire and high temperature performance of limestone. The strategy is based on the assessment of changes in the properties of limestones, assessed with respect to different test conditions including homogenous heating and the standard fire curve. The startegy includes an assessment of the physical parameters and petrographic analysis. The physical analysis includes the determination of the density, porosity, water absorption, ultrasoic pulse velocity, uniaxial compressive strength and indirect tensile strength. The Uniaxial Compressive Strength is determined with reference to BS EN 1926:2006; natural stone test methods – Determination of uniaxial compressive strength, within 24hours of drying or high temperature exposure. The apparent density and the open porosity is determined with reference to the standard BS EN 1936:1999; Natural stone test methods – determination of real denstiy and apparent density, and of total and open proposity. petrographic analysis including polarizing microscope analysis, XRD, SEM. Further analysis is proposed namely the total porosity using the Helium Pycnometer; the pore size distribution through Mercury Intrusion Porosimetry. The startegy furthermore includes colour change analysis and durability analysis of limestone. The research startegy is implimented through an investigation on Maltese and Hungarian limestones conducted over various phases.

3 LIMESTONE SOURCES

In the first phase of the investigation, various limestones from Malta and Hungary are considered for analysis; two Maltese limestones and three Hungarian limestones. The material selected originates from different geological despoits and has varying properties including physical and mineraological characteristics. In the case of Malta, the preliminary investigation refers to the main two varieties of limestone used in construction namely lower Globigerina limestone and Coralline limestone. The investigation is intended to lead to a first scientific understanding of the performance of Maltese limestones when exposed to fire and high temperature. In the case of Hungary, the three limestones selected include Compact Limestone, Oolitic limestone and Travertine, with varying characteristics.

3.1 Globigerina Limestone and Coralline Limestone

Globigerina limestone blocks are extracted from the Lower Globigerina geological formation in Malta, and are used primarily in the construction of load bearing masonry walls. Globigerina limestone is extracted also for other applications in the building industry namely cladding elements. The stone which is extracted from open-pit quarries using mechanical saws is relatively soft and yellow in colour. Variations in quality of Lower Globigerina Limestone is reported from different quarries located in different areas in Malta, and also within the same quarry with depth. The Upper and Lower Coralline limestone geological formations are mainly exploited for the production of aggregate and civil engineering applications. Specific formations are also exploited for the production of cladding elements. Blocks extracted from specific coralline limestone formations were traditionally also used in specific cases in buildings due to better durability and strength of the materials and imporved weathering resistance qualities when compared to the soft globigerina limestone. The upper Coralline Limestone and the Lower Coralline limestone deposits are subdivided into different members. The scope of the first phase of the investigation is to review the main performance characteristics and to define the main paramateters for more detailed investigations. The materials were selected as representative materials of the two main types of limestones, as summarised in Table 1. The Globigerina limestone samples were extracted from rectangular blocks sampled from the same layer in a specific quarry. The Coralline Limestone samples were extracted from boulders extracted from an Upper Coralline deposit in a Coralline limestone aggregate quarry in Malta.

Tab. 1 Origin of Limestone Samples, Malta

Stone Type	**Reference**	**Age**	**Source**
Globigerina limestone	Lower Globigerina Member	Miocene	Ta’Kandja, Malta
Upper Coralline Limestone	Tal-Pitkal Member	Miocene	Mgarr, Malta

3.2 Compact Limestone, Oolitic Limestone & Travertine

The Hungarian limestones investiagted are summarised in Table 2. These materials were selected on the basis of their common use in buildings including historic buildings. Compact limestones in Hungary are mostly Mesozoic to Eocene in age and have a very low porosity. These are mostly used as polished slabs. Porous Miocene limestones are found in four stratigraphic levels in Hungary, but the most widespread one belongs to the Sarmatian age. The porous, mostly oolitic limestone was exploited in the Budapest region in subsurface galleries and quarries (Török 2007). Buildings constructed from this limestone are mostly located in Budapest and in the surrounding areas, including important emblematic monuments from the 19th to the early 20th century such as the Citadella, the Parliament building, the Opera House and various churches. Most Hungarian travertines were deposited from springs in lacustrine environments during the Pleistocene and the materials have been used since the Roman period (1st to 2nd centuries AD). Today two major travertine occurrences are being exploited, one in the north-eastern suburb of Budapest and one which is 40 km NE from Budapest, located in the village of Süttő. In the Parliament building the porous oolitic limestone is replaced by travertine and replicas of ornaments and motives are carved by stone masonry workers.

Tab. 2 Origin of Limestone Samples, Hungary

Stone Type	Age	Source
Compact Limestone	Mesozoic	Budapest
Oolitic Limestone	Miocene	Budapest
Travertine	Pleistocene	Budapest

Fig. 2 Miocene porous oolitic limestone

Fig. 3 Pleistocene travertine

4 INVESTIGATION OF GLOBIGERINA & CORALLINE LIMESTONE

The preliminary investigation intended to assess the performance of the Globigerina and Upper Coralline limestone when exposed to fire and high temperatures is subdivided into two parts conducted in parallel in Malta and Hungary. The first part of the investigation is based on the assessment of stone exposed to Homogenous Heating at different temperatures for a sustained period of time. The testing is conducted in the Civil Engineering Laboratory of the University of Malta. The second part of the investigation is based on the exposure of samples to the standard fire curve, with testing being conducted at the EMI LLC Fire Protection Division in Hungary. The fire exposure with respect to the Standard fire curve (ISO 834) is planned with reference to different conditions including time of exposure. This paper includes the preliminary resultsof specific tests conducted on limestone samples.

4.1 Homogenous Heating of Limestone

The samples were cut to size (50mm cube) from larger building blocks extracted from the quarry. Prior to exposure to high temperature the samples were dried in a ventilated oven at a constant temperature of 70±5°C to constant mass. This was taken to be attained when the differetn between two weighings at an interval of 24±2 h was not greater than 0.1% of the mass of the specimen. After drying, the sampels were stored in a dessicator at 20±5°C until thermal equilibrium was reached. The samples were exposed to the following temepratures; 100°C, 200°C, 400°C, 600°C, 800°C, 1000°C over a period of 6 hours. The specific temperature was attained through a uniform gradient over a period of 1 hour, with increasing temperature from 20°C to the specified temperature. The specified temperature was then kept constant for the 6 hour period. In the first stages of the investigation the sample density and compressive strength were determined. The Uniaxial Compressive Strength was determined with reference to BS EN 1926:2006; natural stone test methods – Determination of uniaxial compressive strength, within 24hours of drying or high temperature exposure.

4.2 Assessment of Globigerina Limestone & Upper Coralline Limestone

Following the exposure to high temperatures through the methodology outlined above a discolouration of the Globigerina limestone was noted. The original sample is characterised by a natural yellow colour. A reddish-brown discolouration was noted once the stone was exposed for 6 hours at 400°C. A grey colour was observed following exposure for 6 hours at 600°C. the colour of the stone became white after exposure for 6 hours at 800°C. The Density of the samples and their compressive strength were observed to decrease with increaing temperature exposure over the 6 hour period, with significant reduction in the uniaxial compresive strength for samples exposed at a temperature of 800°C and 1000°C. The changing density, compressive force and ratio of residual strength to strength at 20°C are summaried in Table 3. The uniaxial compressive strength of Upper Coralline Limestone samples dried to constant mass varied over a range from 65 to 90MPa, but decreased significantly to a range from 10 to 15MPa following exposure at 1000°C for 6 hours. The density of samples decreased by 40% for the same exposure, with the sample turning from its natural grey colour to white. The natural colour of limestone is related to the mineral composition and Chakrabarti reported that in the case of brown or buff-coloured limestone which contains hydrated iron oxide, the material changed colour to pink or reddish brown at 250 – 300°C, and to more reddish at 400°C. The stone becomes a grey-white powder at 800-1000°C (Chakrabarti, 1996). The calcination of calcium carbonate begins at 600°C and proceeds rapidly beyond 800°C. The strength is reported to reduce once calcination occurs. The intrinsic strength of the limestone is reported to remain unchanged in small fires.

Fig. 4 Discolouration of Globigerina limestone Samples from top left to right, bottom left to right: yellow 100°C; yellow 200°C; reddish-brown 400°; grey 600°C; white 800°C; grey-white 1000°C

Tab. 3 Perofrmance of Globigerina limestone – Homogenous Heating

Temperature	**Density**	**Compressive Strength**	**Residual Strength ratio**
°C	kg/m^3	MPa	%
70	1774.67	35.71	100
100	1810.41	33.62	94.14
200	1779.72	35.33	98.93
400	1761.20	31.94	89.45
600	1710.43	28.95	81.07
800	1351.31	10.57	29.60
1000	1063.78	4.24	11.88

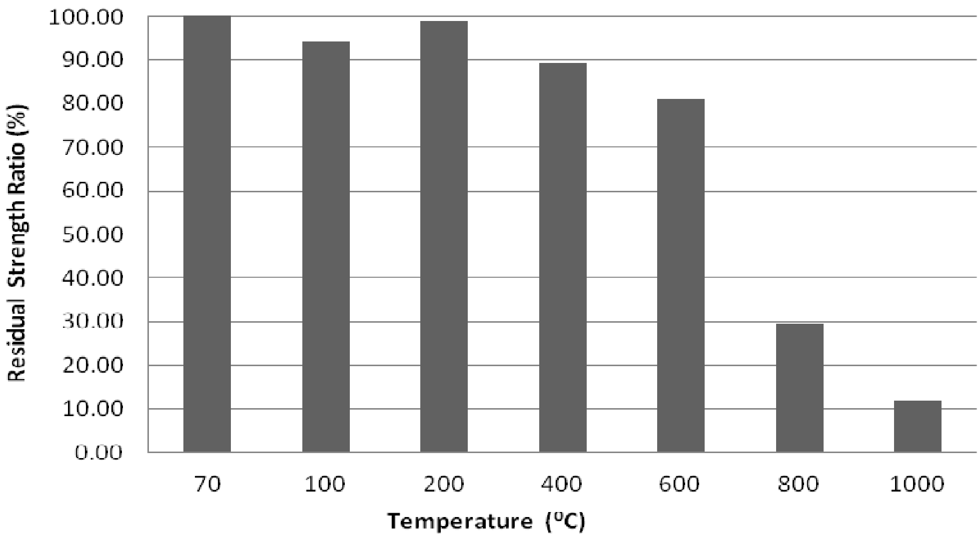

Fig. 5 Residual Compressive Strength

4 CONCLUSION

The Strategy for the assessment of the performance of limestone when exposed to fire and high temperatures is intended to serve as the framweork for the investigation and comparison of different limestones. On the basis of the preliminary investigation it is planned to consider the analysis as outlined in the proposed strategy and also extend the investigation to assess other criteria including; performance in the case of different exposure periods, thermal shock effects and exposure conditions after high temperature exposure. Additional types of limestones within the same class but from different quarries shall also be considered.

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