

Classification of Natural Building Stones

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ABSTRACT

Stones which can be used as natural building materials are being classified in BS 5930 [1] and TS 2513 [2], TS 5695 [3] standards. However, as neither BS 5930 nor TS 2513, TS 5695 can answer the current requirements of the industry; stones are often classified as genesis. There is a need for the comprehensive study which can be used at processing, implementation and marketing of building stones. In this study, natural building stones have been classified with respect to their geological, chemical and physico-mechanic characteristics under six major classes as marble, limestone, travertine, onyx, hard stone and decorative stone. These major groups have further been divided into subclasses. This study on classification of natural building stone materials will be very useful for industrialists, traders and consumers as well as civil engineers, architects and designers. The detailed and basis classification methodology will also bring away the problems resulted from the confusion of classification in the literature.

Keywords: *Natural building stones, Classification, Marble, Limestone, Travertine, Onyx, Hard stone, Decorative stone.*

1. INTRODUCTION

Rock material which is used in the construction of buildings or structures shaped to men's needs is called stone. Gemstones for bracelets and necklaces are not included [4]. Mankind has been using the stone since the beginning of its existence. For many centuries stone has been generating the construction materials and non-compromised form of art for the human being by its strength, durability, elegance, colour and reserved. Many civilizations such as Hittites, Ancient Egyptians, Phrygians, Mesopotamians, Persians, Lydian, Ancient Greeks, Greco Romans, Romans, Seljukians, and Ottomans had used stone for their statues and in architecture which enlighten their own time and survived until today.

Stones are classified into three groups based on their origin of formation; metamorphic, sedimentary, and igneous rocks. However, in industry and commerce, stones are classified into six groups: marble, limestone, travertine, onyx, granite and sandstone. Currently, these geological and industrial classifications of stone are becoming more and more insufficient. Therefore, there is a significant need for a more comprehensive classification of stones as a building material especially for the use of architects and civil engineers. In this study, natural stones are being classified in a different manner. For classification purposes, we assessed their geological, chemical and mechanical properties with effects their ease of cutting and processing, hygiene, aesthetics, structural safety and decay.

2. CLASSIFICATION OF ROCKS

Classification according to their geological origin is one of the most common methods of classification of rocks. According to their origin, rocks are classified as igneous, sedimentary and metamorphic. Igneous or magmatic rocks are primarily crystallized from a fiery fluid silicate melt, taking place either deep below the earth's surface or at the surface. Granite and basalt are the most common members of this group [4,5] Igneous rocks have been classified with respect to their textures, structures, content of silica and colour by a number of scientists. The most commonly accepted classification and nomenclature are made by Streckeisen [6,7,8]. Sedimentary rocks are formed by the concentration of inorganic or organic debris of variable size and shape, deposited by mechanical means or by chemical precipitation [4]. These sedimentary rocks have been classified according to their type of sedimentation, grain shape, cement type, CaCO_3 , clay and silica content and layer thickness. In classification of sedimentary rocks, mostly the studies of Folk, Dunham and Pettijohn et al. are being accepted [9-14]. In addition to those mentioned, Fookes and Higginbottom have classified sedimentary rocks with respect to their calcite and dolomite contents [15]. Metamorphic rocks are igneous or sedimentary rocks recrystallized by the effect of temperature and pressure [4]. Yardley classified that group as contact, regional, dynamic, hydrothermal and impact metamorphism rocks [16]. Grain size is also often used for classification of metamorphic rocks.

Another methodology which is often utilized for rock classification is separation rocks with respect to their physical and mechanical properties. Rocks are classified by their uniaxial [2,17,18], bending [2], point load [19] strengths and porosity [20,21]. They are also being classified as hard or soft depending on their ability to crack geologist hammer. All known rock classifications can only be used in engineering geology, geotechnical and mining industries but not in building industry.

3. BUILDING STONES

The common rock classifications summarized above are not sufficient for classification of stones used in building industry. Classification is totally different in natural stone industry and trade. In these sectors, more practical and common nomenclatures are being used. In natural stone industry and commerce, carbonate rocks that can yield commercially viable blocks, can be dimensioned and polished, and be used in buildings are all called marble. The term granite is used for any strong or hard igneous rocks and even for some metamorphic rocks. Commercially, granite includes basic igneous rocks, which do not contain quartz, such as basalt, dolerite. Gabbros often called black granite and the metamorphic rock, gneiss. However, true granite is a igneous rock largely composed of an interlocking mass of crystalline grains of three minerals; quartz, feldspar, and mica. Travertine is a general term given to lacustrine and shallow lacustrine younger limestones that is a sedimentary rock. Travertine is highly porous rock, often banded structure. True travertine is a freshwater limestone formed on land from hot springs. Onyx is a massif or banded sedimentary rock contains calcite or aragonite formed by hot and cold water that are rich in mineral. True onyx is a chalcedony. Slate is used for any rock that exfoliates into thin slabs or roof tiles. True slate are metamorphic rocks composed originally of fine-grained particles (silt, clay) tightly compressed together and hardened [22]. In this context, Winkler summarized the major common rock types used in stone industry [4]. Smith classified the rocks according to their mass structure and hardness which in fact effect extraction and processing performance [22].

3.1 Stone Classifications

For architects, civil engineers and final users, stones' colour, aesthetics, hygiene, its ability to be customized and decay are important. Most of the time, designers, owners and applicators in a project are under the influence of their past experiences, habits and other reference projects. This causes errors in production, false applications and other problems as well. In stone industry, all procurement, timing and quality aspects are equally important. These might yield problems between producers, traders, architects and final users. One should not ignore geological parameters and physico-mechanic properties of the stone and only concentrate on aesthetics. Therefore, there is a need for a new classification where both material characteristics and industrial and architectural properties of the stone are taken into account. In Table 1, natural building stones have been classified as marble, limestone, travertine, onyx, hard stone and decorative stone. Those stones are classified at Table 2-7.

Table 1: Classification of natural building stones

Marble	Limestone	Travertine	Onyx	Hard Stone	Decorative Stone
very compact porosity < 0.5%	compact 0.5% <porosity< 1%	porous 1% <porosity< 5%	high porous 5% <porosity< 10%	very high porous 10% <porosity	
treatable SiO ₂ < 2%	moderate treatable 2% <SiO ₂ < 5%	hard treatable 5% <SiO ₂ < 25%	very hard treatable 25% <SiO ₂ < 60%	super hard treatable 60% <SiO ₂	

Porosity and SiO₂ is important for all building stones. Stones are classified as very compact, compact, porous, high porous and very high porous. When porosity increases, durability of stone decrease and the effect of thawing-freezing, biological and environmental attacks increase as decay accelerate. Increase of porosity also affects the hygiene and aesthetics of the stone negatively. On the other hand, polishing quality of porous stones is lower. Filling materials can be used in stones that are porous like travertine, and sealers can be used in

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stones which has significant clay content and absorbing water. However, filling material and sealer can change the aspect of the stone and may cause some fabrication and application problems. Therefore, costs increase with increasing porosity. Stones are classified as treatable, moderate treatable, hard treatable, very hard treatable and super hard treatable according to their SiO_2 content (Table 1). SiO_2 is an important parameter that increases extraction and processing costs of the stone. There is need for sophisticated machinery for extraction and processing of stones with SiO_2 content other than treatable, moderate treatable stones. Existence of SiO_2 in marble and limestones is a rare event and it jeopardizes quality in some processes like polishing and chamfering. On the other hand, SiO_2 increases the stones durability and improves their strength.

According to their MgO content (Table 2) marbles are classified as calcitic, low magnesian and dolomitic. MgO content is also important in projects. The allurements of MgO ions is greater than other components. In places that will be exposed to liquids like water, rain, coffee or dust, stones with lower MgO content should be used. Fluids and dust affects the stone and changes the colour to a darker tone and yields a patchy look. In colder places, dolomitic stones are affected from frost more easily. However, MgO increases the hardness and strength of the stone.

Table 2: Summary of the marbles used in the building

Calcitic		Low Magnesian 4% <MgO< 10%		Dolomitic 10% <MgO	
very fine crystalline < 150 mm	fine crystalline 150 mm <grain< 800 mm	medium crystalline 800 mm <grain< 2 mm	coarse crystalline 2 mm <grain< 5 mm	very coarse crystalline 5 mm <	
bituminous breccia banded laminated					

Size of crystals is important for marbles. In industry and commerce, marble are also called crystal or crystallized marble. By increasing of crystal size, toughness, attraction and polish taking decreases and porosity, water absorption, processing costs increases, aging of the stone accelerates.

Bitumen is important for marble, limestone and travertine. Stone that contain bitumen are of black, grey-black colour. One can smell bitumen during extraction and processing of stone but it doesn't smell after installation. Bituminous stones are affected from sun, their black colour fade gradually.

Breccia and conglomerate adds marble, limestone and sandstones extra movement and attraction. On the other hand, breccia and conglomerate content causes important problems during processing. They reduce chamfering quality and increases costs. Breccia and conglomerate stones should be used in custom size rather than cut-to-size in projects. This stones are also affected more from atmosphere.

Banded texture is related with stone initial deposition. Banded structure is observed most in travertines and onyxes and least in igneous stones. Colour differences in, between, and out of bands adds attraction and aesthetics to the stone. Symmetric structures like vein-cut and open-book are more valuable than cross-cut. Bands in stone add depth and movement to the project. On the other hand, differences in and between bands reduces stone productivity and

processing quality. Strength of bonds between the bands and pores along the edges along the bands affect the resistance of onyx and travertine.

Layer formations are observed at the stones other than the igneous ones. All block traders and people working in cooperation to block traders should be very careful when they are working with layered stones. Structural and textural differences between layers affect projects negatively. One should know the textural differences between layers in advance in large size and prestigious projects. Every material should look like a part of a whole and act as a complementary unit. Marble and similar metamorphic decorative stones are used by separating them in their natural borders of laminates. Slate is the most commonly known example of this type of a usage. The thickness of lamination is less than 6 cm [1]. Lamination decreases productivity significantly; however brushing yields better results and improves attraction in laminated stones. If not enough attention is paid, lineation also increases the costs of production. Very few producer, trader, architect and civil engineer recognize the lineation and pay enough attention to it. Lined stones, especially lined sandstone add depth to the project work. Stones being cut parallel and perpendicular to the lineation, if laid together create a wave movement effect.

Limestones are the second most widely used stones after hard stones around the globe (Table 3). Limestones are classified as recrystallized, micritic, fossils and marl. Toughness of recrystallized limestone is higher and their porosities are lower generally. Characteristic of micritic limestone are variable and fissures are often observed. Containing fossils are one of the general characteristics of limestones. On the other hand, some particular limestones contain more fossils than the others. Size of the fossils and their homogeneity are also important. Larger size (1 cm) fossils might yield decorative looks but their reserves of fossil accumulations are generally pretty little. Fossils cause problems in chamfering and polishing. Marl contains clay. As clay complicates polishing, honing should be used. Clay also decreases toughness of the stone and increases porosity and water absorption. Marl get affected from environmental factors a lot. Marl should not be used outdoor areas and on floors. MgO content is also an important parameter for limestones. Limestones and travertines are often classified as light and dark. With the increase of CaO and MgO content, stone colour gets lighter.

Table 3: Summary of the limestones used in the building

Recrystallized	Micritic	Fossils	Marl
pure	low magnesian 4% <MgO< 10%		dolomitic 10% <MgO
dark			light
	breccia layered banded bituminous		

Travertines are classified as massive and layered in Table 4. Massive travertine is tougher and their porosities are usually lower than layered travertine. Massive travertines are also more homogenic. The most important issue with layered travertines is the strength bond between layers. Sand and clay accumulated between layer boundaries decreases efficiency a lot and cause surface and polish problems. Sandy travertine which has sand content in the mass should not be polished and should never be laid on the floor with polished finish. Sand particles separate from the surface during polishing operation and scratch the surface in place.

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Plant fossils and shells are observed abundantly in travertines. Plant fossilised travertines are usually dark coloured, they are not homogeneous and they have higher porosities. Some shells may contain SiO_2 . Generally, shells also do cause problems during polishing and chamfering. Shells with homogeneous distribution and uniform size yield a decorative look on the stone. Travertines with plant fossils and shells have lower deposit reserves.

Table 4: Summary of the travertines used in the building

Massive	Layered
sandy banded	
plant fossils dark	shells light
bituminous	

The most important characteristics of onyxes that differs them from other stones is their semi-transparency. Some marbles also are semi-transparent. However, transparency of onyx is significantly higher. Onyxes are classified as calcite, aragonite and alabaster (Table 5). Their hardness is alabaster, calcite and aragonite, respectively. Alabaster is gypsum and should not be used outdoors. Banded onyxes add depth to the project where watered onyxes add motion.

Table 5: Summary of the onyxes used in the building

Calcite	Aragonite	Alabaster
massive	watered	banded
layered		

Hard stones are classified as sandstone, igneous stones, gneiss and migmatite in Table 6. Hard stones are the first stone that is known that have been used by humanity and they are the most abundant type of stone with the biggest reserves. Any form of surface and edge finish like flaming can be used on hard stones. More sophisticated machinery and equipment are being used during extraction and processing of hard stones which contain hard minerals like quartz and feldspar. Because of their durability, hard stones are both used as masonry block and kerb as well as panel. Hard stones have high permeability. Imbibition of water and rain into the material increases the affect of biological and environmental factors on these stones. As with other type of stones, the grain size decrease so does porosity and durability increases. By the increase of grain size, processing of stones becomes more difficult and processing costs increase.

Table 6: Summary of the hard stones used in the building

Sandstone		Igneous Stone								Gneiss	Migmatite
clay	carbonate	granite	syenite	labradorite	diabase	gabbro	andesite	basalt		layered	
massive	layered										
breccia fossils											
		banded lined									
very fine grain < 0.1 mm		fine grain 0.1 mm < grain < 1 mm		medium grain 1 mm < grain < 4 mm		coarse grain 4 mm <					

Decorative stones except serpentine and pebble are used as sawn masonry blocks or by splitting from their lamination borders (Table 7). Technological advancement and search for new and different stones and finishes enabled those stones to be used in strip and slab forms.

Serpentine are used polished. Talk and fissure content in serpentine obstructs outdoor use. In addition to that, serpentine are affected from sunlight and loses their colour shortly. Pebble and other stones in chip form are usually used at garden decoration. Recently, pebbles are being used outdoors being fixed on concrete.

Table 7: Summary of the decorative stones used in the building

Schist	Calc-schist	Slate	Phyllite	Hornfels	Tuff	Serpentine	Pebble
laminated							
lined banded							
layered							

4. CONCLUSIONS

Classification of building stones in Table 1 and Table 2-6 are being prepared to enable usage of building stones accurately, correctly and precisely by trader, architect, civil engineer and end user. This classification of stones that have been done will reduce problems in the chain of trader-supplier-investor-architect-civil engineer-end user. The classification is important by means of increasing usage of natural stones and decreasing of related costs and building an internationally accepted nomenclature. Classification of building stones will prevent confusion of terminology at industry and commerce. The classification will also help projects to be functional, aesthetic, hygienic and economical.

Acknowledgments

The author would like to thank Bora Akdeniz for his reviews that improved the manuscript.

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