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PROJECT CO-ORDINATOR:

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- **CEVALOR, P**
- **OERLIKON PRECISION LASER S.A., CH**

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TITLE: # CUTTING AND TREATMENT OF MARBLES WITH LASERS

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ABSTRACT

The project concerned the development, optimisation and testing of laser cutting and treatment techniques in order to cut and modify the surface of marble plates of different thickness in various geometrical shapes by achieving cutting speeds and surface quality acceptable by industrial standards.

Laser parameters (such as power, cutting speed, focal distance, assist gas etc.) have been optimised for $C0_2$ and Nd-YAG lasers. Cutting, de-polishing, marking, lettering and drilling of Greek and Portuguese marbles with CO_2 lasers has been successfully investigated under atmospheric "dry" conditions and in "submerged" conditions using a specially developed high pressure laser head in a sedimentation tank under water.

The project has started on the 1st of February 1993 and has been completed on the 3 1st of July 1995, The Consortium involved six participants from four European countries, namely General Marble Ltd (co-ordinator) and the Institute of Geology and Mineral Exploration from Greece, the Applications und Technikzentrum für Energieverfahrens, Umwelt und Strömungsmechanik from Germany, the Instituto de Soldadura e Qualidade and CEVALOR from Portugal and OERLIKON PRECISION LASER SA from Switzerland.

1. INTRODUCTION

Marbles represent a national asset for all E.U. Mediterranean countries and have wide applications as construction and decorative materials. More recently, white marble powder, which is nearly pure calcium carbonate has found application as filler and whitener in the paper, plastics, polymer and paint industries.

The presently used mechanical cutting methods are time and material consuming and limit cutting capabilities such as accuracy, speed and pattern flexibility, For decorative and general applications non-linear shapes are frequently required, which are traditionally cut with diamond discs and emery lathes. Improvements can be achieved, when introducing laser cutting technology, due to the high versatility of the equipment in producing irregular shapes and novel products with cutting speeds higher than the traditional ones.

Although laser technology for cutting, welding and surface treatment has been significantly developed and applied during the last ten years for ferrous and non-ferrous materials, there has not been an equivalent development in the cutting and treatment of stones.

The scientific and technical results obtained within the frame of the BR-5062 project have focused around four major focal points:

* the ability to cut marbles with lasers,
* the effects of the laser treatment on surface modifications (marking, lettering, de-polishing, engraving),
* the material response to the effects of a laser beam and
* the industrial application of the methodology.

The technical developments achieved during the BE-5062 project can be summarised as follows:

- Sampling of Greek marbles has been performed for a wide variety of Greek marbles. The physical, mineralogical and petrographical properties of the samples have been established.
- Nine (9) different types of Greek and Portuguese marble plates of 10 mm, 20 mm, and 30 mm thickness have been subjected to laser linear and non-linear cutting, drilling, lettering, marking and masked and non-masked de-polishing. Cutting, drilling and surface treatment tests have been performed in atmospheric {"dry"} and underwater ("sub-merged") conditions and with different types of lasers.
- Both "dry" and "sub-merged" cutting of marbles with lasers have been optimised in order to increase cutting efficiency and retain the fine marble powder produced during cutting. Namely, the laser type, laser power and operating conditions that optimise the cutting process and simultaneously produce marble powder below 20 mm in size have been established.
- Extensive investigations have been performed in order to evaluate the process parameters (CO_2-DC-laser, CO_2-HF-laser, laser power, focus location, cutting gas pressure, water level) and to analyse their influence on the quality of the cut and the cutting speed for different plate thickness and marble qualities, It has been examined whether the thermal treatment of the marble surface with a laser affects the material structure.
- Based on the above results experiments have been carried out to cut marble plates in complex geometrical shapes. Guidelines have been established to adjust the process parameters for the requirements for cutting complex geometries. Final optimisation has lead to guidelines for scaling up to an industrial scale.
- A "sub-merged" laser cutting system for marble plates has been developed and tested . In order to supply sufficient resist gas for laser cutting of a dry material surface, a high pressure nozzle has been developed, based on previous experience. This nozzle has been designed and adapted to submerged operation in the tank It is equipped with a nozzle to provide a pressure gas flow preventing contamination of the optics and the creation of a water film on the marble plates. The reliability in operation has been proved experimentally. To prevent dust dissipation to the environment the cutting operation is carried out in a special sedimentation water tank equipped with a removable support for marble plates. The marble dust produced during laser cutting is collected in the sedimentation tank,

➲ A model plant and a demonstration laser system have been assembled comprising an OPL C02 laser, a special laser head and powder retention tank developed within the project for underwater cutting, traversing tables, cranes, belts, etc. The pilot plant has been set up at the premises of General Marble Ltd. with the aim to investigate the industrial production of marble plates and tiles cut with the help of laser beams, and to perform an economic evaluation of the process in order to assess its feasibility for general industrial application. Technical difficulties did not permit the completion of this latter task.

The advantages laser cutting and treatment of marbles can offer are that no mechanical stresses exerted along the cut edge, there is no direct contact between material and cutting head, there is no limitation on cut forms, shapes and dimensions of cuts and finally drilling and cutting are achieved by the same laser head. In comparison to other cutting techniques (such as diamond doped saw, wire saws, water jet cutting) high cutting rates can be achieved and the dust produced will not contain any additional abrasive materials originating from saw material or components (e.g. as in the case of the water jet cutting). One main advantage of laser cutting is the ability to cut thin marble plates, which is up to date very difficult because of the mechanical stresses generated by the mechanical cutting methods. Thin marble plates are often used for tiles for furnishing office rooms etc., and the production by conventional sawing exhibits high scrap to finish ratios.

2. TECHNICAL DESCRIPTION

The methodology of the BE-5062 project has been as follows:

- Selection of laser type and evaluation of laser cutting parameters. Feasibility of cutting marbles with lasers (in particular CO_2-lasers).
- Design and construction of a special water tank for submerged cutting.
- Development of a dedicated high pressure nozzle for the under water cutting of marbles.
- Optimisation of cutting process both for “dry” and “submerged” cutting conditions.
- Investigation of de-polishing, marking and lettering of marbles and granites.
- Assembly and installation of a laser marble-cutting pilot plant and testing of the proposed pilot system under industrial conditions.
- Economic evaluation of the production and cost parameters,

The selection of the various marble types that have been examined during the project has been based on marble value and demand, reserves, and chemical and mineralogical marble composition.

Four types of Portuguese marbles *were* used for the laser cutting tests, namely White marble (Branco Pardais), Pink Marble (Rosa de Borba), Dark Ruivina, and Moca Creme - Relvinha.

The following Greek marbles have been selected for investigation, referred to herein according to the Hellenic Marble Directory: Ash coloured Crystalline of Thassos, White of Limenas Thassos, Pink of Lafkos (Aegeo Pink}, White of Dionissos-Penteli, Beige Breccia of Mycenae, Green of Polydendri-Imathia, Pighes and Volakas.

During the course of the project both "dry" and “submerged” cutting of marbles with lasers have been optimised in order to increase cutting efficiency. Extensive investigations have been performed that evaluated the process parameters, For CO_2-DC-lasers, CO_2-HF-lasers and Nd-YAG

lasers the effects of varying laser power, focus location, cutting gas pressure have been investigated with regard to their influence on the cutting speeds and final cut surface quality, The experiments have been performed for different marble plate thickness and marble qualities.

Additionally, the thermal effects of laser cutting and treatment on the marble crystal structure and porosity have been thoroughly investigated, by performing temperature measurements, flow visualisation for the underwater cutting and by analysing the cut surfaces. Based on the obtained results experiments have been conducted to cut marble plates in various geometrical shapes, e.g. circles, acute angles etc.

Guidelines have been established to adjust the process parameters for the requirements of cutting complex geometries and of marking, lettering or de-polishing marble plates with CO2 lasers.

3. OVERVIEW OF ACHIEVED RESULTS OF LASER CUTTING OF MARBLES

The major results of the research work performed during the project areas follows:

- **Cutting:** The CO_2 laser is more suitable for marble cutting than other types of lasers, since a high power level is required to volatilise the marble. It is a process that can induce cracks, depending highly on the marble type and on the laser parameters. For both "dry" and "underwater" cutting, the cutting speed can be significantly affected by the marble type. The maximum cutting speed and the best cutting quality are higher for marbles with higher levels of crystallinity. In general, the investigated Greek marbles exhibited better laser cutting behaviour than the Portuguese marbles and the cutting behaviour of dolomitic marbles is better than this of the calcitic marbles. The Greek marbles "White of Limenas Thassos" and 'Pighes", due to the fact that their composition is based on magnesium oxide (dolomitic marbles), are suitable to be cut by laser, They have exhibited no significant fragility of the cutting surface and surrounding areas, Dolomitic marbles cover at present more than **60°/0** of the Greek marble production.
- The smoothness of the cutting-trace line is in general very good. For dolomitic marbles it is a little better than this of the calcitic marbles. This can be explained by the higher thermal conductivity of the dolomitic marbles, For the higher **cutting speeds**, a lower amount of detached carbonate grains (calcite, dolomite) is formed, This fact is due to the lower values of the thermal stresses exerted with higher cutting-speeds.
- Laser **cutting** of **linear** and non-linear **shapes** (e.g. lavatory table tops, oval shapes, sink holes etc.) is advantageous and faster than with Abrasive Water Jet cutting or cutting with mechanical means for the dolomitic marble plates with thickness up to 20 mm. The heat affected zone for most of the marble types investigated is such that it can be easily removed during industrial cutting (e.g. during bevelling with mechanical means) and its fragility does not restrict the industrial application of laser cutting of marbles. The maximum speed obtained for the linear cuts of dolomitic marbles is too high to perform non-linear cuts in the calcitic marbles. On dolomitic marbles the same speed can be used for linear and non-linear cuts.
- **Drilling:** The use of continuous wave allows a faster drilling time for the Portuguese marble Rosa de Borba. For the Greek marbles the pulsed beam reduces the drilling time. There is no significant influence of the lens focal length on the drill diameter.

- The laser marking produces a permanent mark on the marble, which is constituted of fragile material which can be easily removed. However, the type of marble affects the quality. The CO_2 laser is more suitable than Nd:YAG laser for marking marbles due to the lower level of energy density. Marking originates a unique visual contrast which is impossible to achieve with any other method. It is possible to mark at high speeds with high versatility of shapes, including characters. Laser marking and lettering can be industrially applied in placing a permanent stamp (e.g. the EU -mark) on various types of natural stones.

- Laser **de-polishing** can be industrially applied for the creation of anti-slipping surfaces (e.g. for stair cases). Laser de-polishing can be cheaper than sand-blasting or flame-jet techniques. Marking and de-polishing behaviour has been fairly good for all types of marbles examined. The best marble types are the dolomitic (Thassos White and Pighes) since the tracks present depth and width homogeneity, and allow high speeds of laser de-polishing,

- **Characteristics of marble** powder: The powder produced during laser cutting for the calcitic marbles consists mainly of Portlandite ($Ca(OH)_2$) and calcite, which is detached during cutting. On all the cut surface, a powder crust of the above minerals was formed. For the dolomitic marbles the powder-crust consists of a mixture of portlandite, lime, periclase, dolomite and calcite. The deserved dolomite and calcite are detached primary raw material, Lime and periclase are products of the thermal decomposition of the dolomite marbles. Portlandite is secondary formation by the hydration of lime. Brucite ($Mg(OH)_2$) was not observed.

- The **watery sludge (mud)** remaining after under-water treatment of dolomitic marbles, consists mainly of Brucite ($Mg(OH)_2$), calcite and a little dolomite. Portlandite was not observed The mean grain size is less than 13 μm, which makes it appropriate for use in the paint and plastics industry. The similar powder from calcite marbles can be used in the paper industry, after further grinding to grain sizes below 2 μm.

4. CONCLUSIONS

- The main innovative results of the project are:
  - Definition of optimised laser cutting procedures (submerged and dry) for wide range of Greek and Portuguese dolomitic and calcite marbles.
  - Development of new techniques for marbles surface processing: lettering, de-polishing and marking.
  - Pilot plant for submerged laser cutting of marbles,

- The advantages laser cutting and treatment of marbles can offer are:
  - no mechanical stresses exerted along the cut edge
  - there is no direct contact between material and cutting head
  - there is no limitation on cut forms. shapes and dimensions of cuts
  - lettering, de-polishing, marking, drilling and cutting are achieved by the same laser head.

- Laser cutting and treatment of marbles, and more generally of natural stones, is a quite innovative technique which can be potentially applied at an industrial level to produce new forms of products.

- ☞ Immediate application of the methodology is hindered by:
  - ✓ cost (most European marble companies are S.M.E.'s with **limited** investment capacity).
  - ✓ lack of market analysis and economic evaluation for new marble products.
  - ✓ limited data regarding behaviour of wide range of natural stones when treated with lasers.
- @- Laser methodologies can offer combined cutting and surface treatment of marbles.
- ☞ Laser methodologies can improve both environmental aspects (e.g. reduction of marble dust) and working conditions.
- ☞ Japan and USA have started applying laser methodologies to the treatment of natural stones and the European market should be prepared for the competition.

5. ACKNOWLEDGEMENTS

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