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high-pressure abrasive-water jet
spatial superficial material forming

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CREATION OF BAS-RELIEF BASING ON PHOTOGRAPHY USING HIGH-PRESSURE ABRASIVE-WATER JET

Presented technology of spatial superficial material forming based on flat virtual image (picture) luminance is a new, original own application of high-pressure abrasive-water jet forming. Basis of spatial forming of ceramic and rock materials with high-pressure abrasive-water jet in conjunction with depth and jet velocity parameters are described in. It was built a control system and developed adequate algorithms allowing the 3D sculpturing operation of different complex objects to be mechanized.

1. INTRODUCTION

The method of high-pressure abrasive-water jet designed for surface forming is a technology with wide range of applications. Thanks to unusual forming features of water jet that never causes any structural changes of forming material, from the very beginning it was used to extracting and cutting of rock materials, which are relatively sensitive to thermal shocks. In early 80's, the high-pressure water jet admixed with abrasives using injector method was used for cutting of rock materials. Using different kind of high-pressure abrasive-water jets [1], a technological conditions and efficiency of different abrasive materials were optimized. After few years there were developed also new efficient methods of abrasive-water jet cutting with admixture of suspension abrasive-water accelerated in lower working pressures [2]. All that caused that such jetting methods may successfully compete with traditional methods of materials dividing last years.

Abrasive-water jetting process research [9], especially interaction of abrasive grains in the collision zone with forming material [11] let to understand the mechanism of abrasive-water jet cutting as well as model shaping [10] and simulating of jet possibilities [4,13]. Special attention is devoted to accuracy and quality of formed surface [3,12] because it decides of smoothness aspect of rock surface processing [8], which are built of irregular spacing ingredients with different hardness and resistance on water jet erosion. Presented paper is extended continuation of earliest attempt [5] of three-dimensional forming of rocky materials surface using high-pressure abrasive-water jet basing on luminance of flat virtual image (2D picture).

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2. IDEA OF THREE-DIMENSIONAL MATERIAL FORMING

From the very beginning a method of synchronic co-operation was used for three-dimensional material forming that consist of the following systems:

- imaging system,
- converting-steering system,
- active control system,
- technological imaging system.

General view of such experimental stand and equipment is presented in Fig. 1.

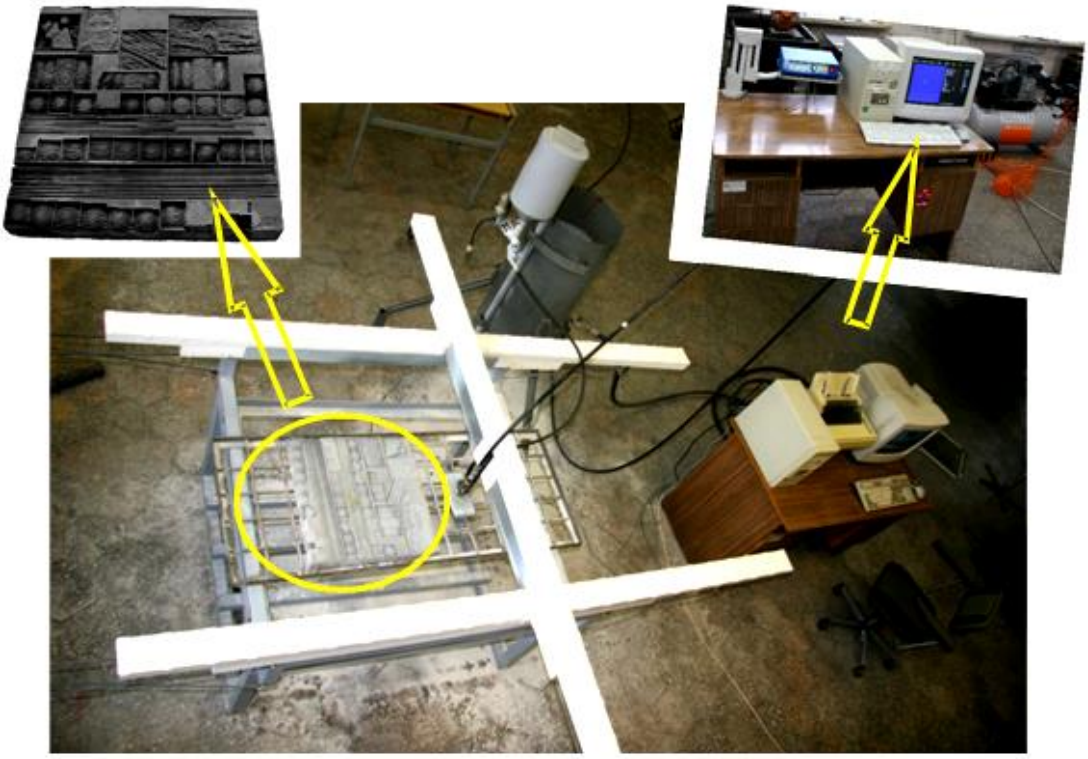

Fig. 1. General view of technological stand and equipment located in the treatment zone

Initial experiment effects [5] let to elaborate the following method. Three-dimensional forming of flat surface materials have on purpose obtainment of real three dimensional object (being perspective bas-relief) is putting into practice by perpendicular high-pressure abrasive-water jet. Dependence of diversified depth is taken advantage in this process from jet feed rate, defined on the base of flat virtual image luminance being discreet package of points written down on palette of grey tints [6]. Having virtual image that is electronic photo of real object or artificial computer flat picture, by changing abrasive-water jet feed rate v_p, it is possible to restore quasi 3D-spatial illusion of real object. Such processing relies on dimensional passaging of forming surface by multiple, parallel transitions of high-pressure abrasive-water jet [7].

At instead of application perplexing in realization dynamic process control, proper model of direct conjugation of feed rate v_p with depth g of material machining about definite characteristic $v_p(g)$ was introduced. Really, however it is used model f(g), frequency of stepping motor versus depth, which introduced for program steering presents individual for given material process of machining model [6]. It is universal most following power model:

$$f = a \cdot g^b \tag{1}$$

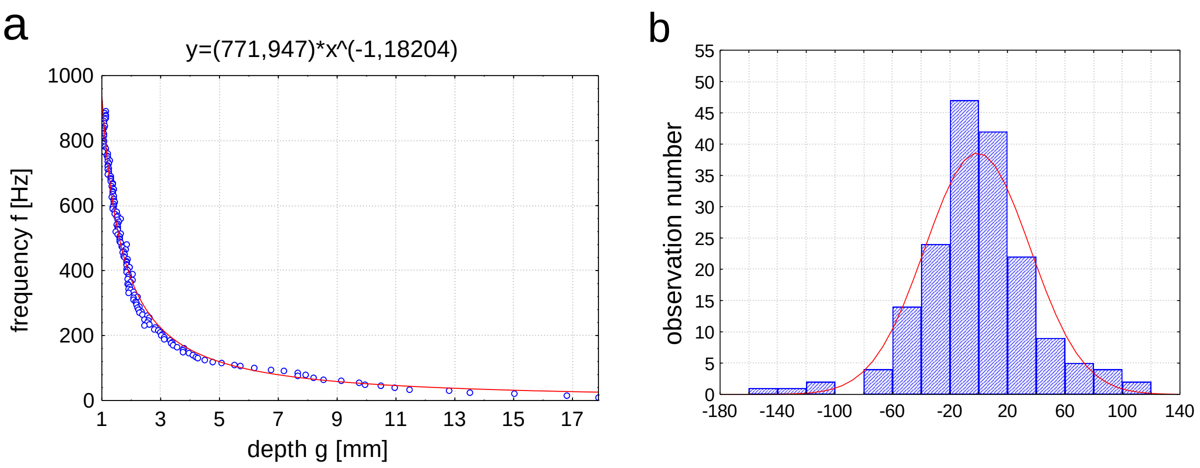

Fig. 2. Experimental results of forming model (a) and exemplary frequency distribution (b)

Above model (exemplary shown in Fig. 2) application simplifies steering model and increases machining accuracy because it directly enables to obtain assigned depth.
Such kind operations of surfaces forming are carried in three following steps:

1. The image is scanned in grey tint and in proper resolution with assistance of scanner from definite source e.g. photo.
2. Emerged "image" (in the form of file bitmap) has been processed on feed rate but same on time of jet interaction on forming material.
3. Performing biaxial system of working fix-up (plotter) executes scanning moves, which were assigned by steering program, causing movement of abrasive-water head with different feed rate and correspondingly diversified material forming.

3. PROCEDURE OF THE RESEARCH

To realize three-dimensional mapping (sculpturing) of flat image, e.g. photo in material processed, it is necessary to synchronize performance of all working systems, on test bed folding, which block scheme is presented on Fig. 3. Basic technological system, on base of high-pressure water pump built, owes special working head coherent with original abrasive feeder. Properly programmed x-y performing system steers working head relocation.

Condition characteristic of carried basic research are presented in Tab. 1. Mainly cement plates were applicable for three dimensional surface forming.

It was carried out in such conditions testing of flat black and white image mapping system on spatial surface of forming material. To evaluate quality and efficiency of mapped virtual image as well as to determine proceeding effects in forming zone, there was applied virtual model in the form of part about 16 mm diameter sphere (Fig. 4a.).

Symmetry around axis by its center crossing is an advantage of type of this model that enables researching obtained spatial object symmetry and determination of reflected jet interaction grade on earlier formed material.

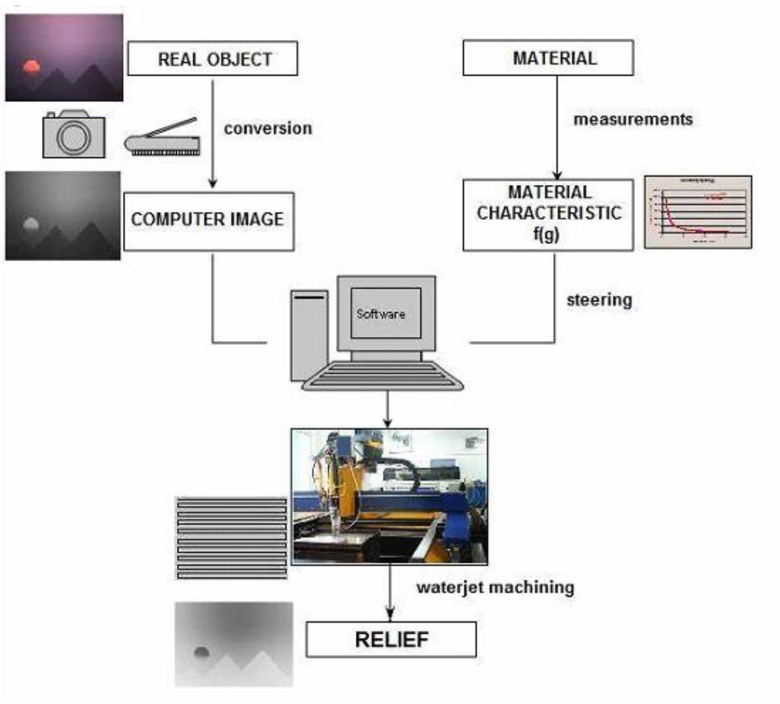

Fig. 3. 3D material forming block scheme with utilization of flat virtual object luminance

Table. 1. Characteristic of basic research condition

Basic water pressure	10 MPa
Nominal water pump efficiency	12 l/min
Abrasive type	sand quartz #0,4÷0,8 mm
Abrasive flow rate	3 g/s
Water nozzle diameter	0,7 mm
Mixing nozzle diameter and length	Φ2 x 51 mm
Cutting plotter working ranger	axis x = 1000 mm, axis y = 1000 mm
Head (traveling speed) range	0,1÷9,6 mm/s
Basis forming material	cement plate 2:1
Erosion depth	0,9÷25 mm

There was identify during such measurements that in different forming places of spherical model, reflected “ricochet jet” interacts to different manner on earlier formed surface, causing local material furrows (Fig. 4b.). Therefore, there must be put into use an allowance adequately rectified to the place of shower and ricochet reflected jet interaction, at exact forming.

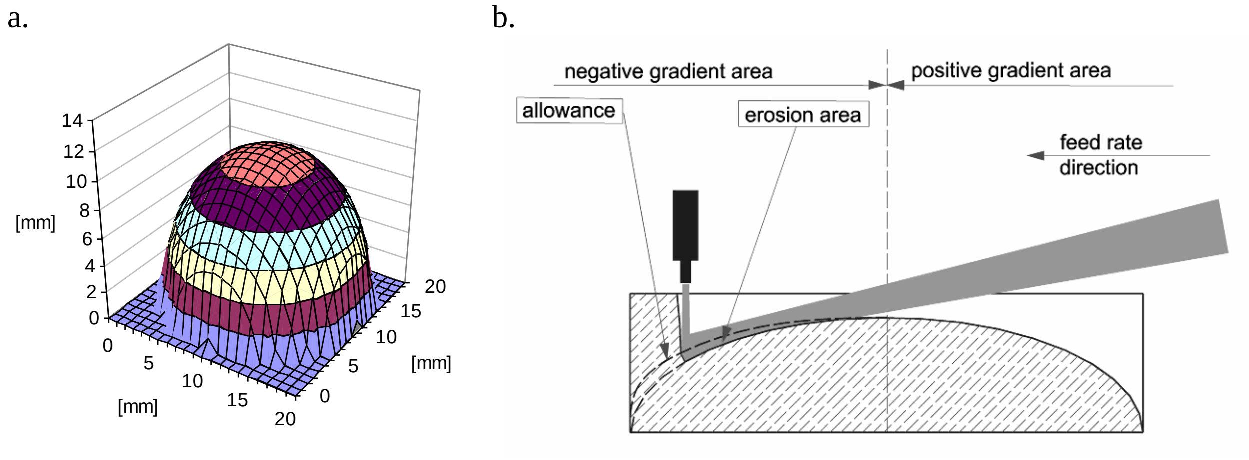

Fig. 4. Ball virtual model (a) and correction of its forming manner (b) versus erosion point (localization)

Such correction is possible to carry out by modification of algorithm subordinating model selection from positive or negative gradient depths realized in turn. It requires elaboration process of model f(g, δ), in which δ means gradient processed point successively. For a range of examined parameters variables, such a model can be expressed as following relation:

$$f = 789g^{-1,2589} + 4\delta \qquad (2)$$

Moreover, for making optimum steering on such forming process it is necessary to divide it on rough and finishing surface forming. It is possible to carry operation of processing at double (Fig. 5): moving jet perpendicularly to remained after machining walls (called orthogonal forming process) or displacing it directly over these walls (called parallel forming process).

To evaluate traces of formed surface structure and its roughness a JOEL JMS-S1 scanning microscope and TalySurf CLI 2000 spatial surface analyzer were used for. Scanning gotten object with laser head, according to Taly-Map software, received real object is converted on digital form being set of points in space.

Basic experiments of three dimensional forming of ceramic objects using high-pressure abrasive-water jet steered according to luminance of virtual object were performed applying above – mentioned measuring hardware and carry methodic of research. It is possible to single out them in results of research have on purpose testing quality and accuracy of processing as well as economic applications of such forming methods.

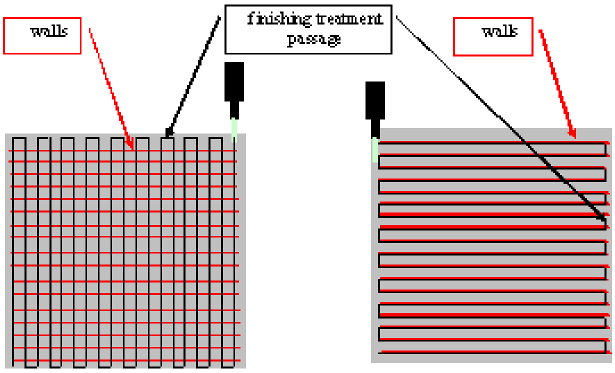

Fig. 5. Scheme of path system in finishing process: a – orthogonal, b – parallel

4. EXAMS OF TREATMENT QUALITY AND ACCURACY

Quality and accuracy testing of 3D different kind of rock objects formed by high-pressure abrasive-water jet steered according to luminance of virtual image is the main purpose of this research. Three-dimensional geometric structures of surfaces of balls can be examples of results of such research, formed different methods, which is present in Fig. 6.

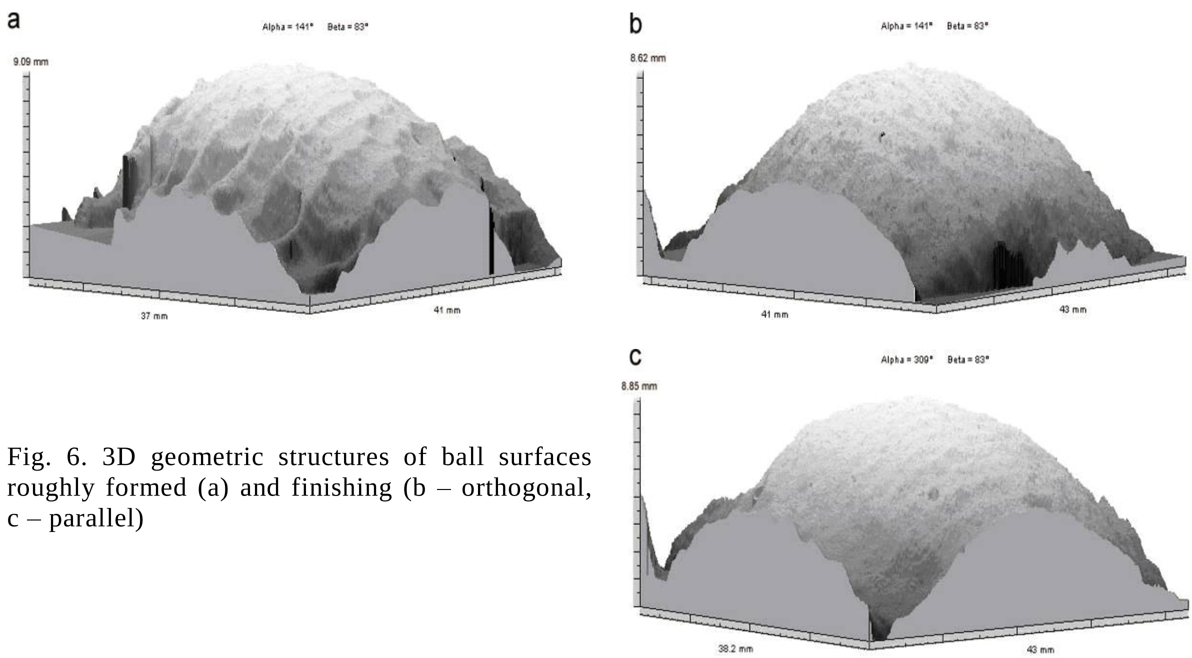

Fig. 6. 3D geometric structures of ball surfaces roughly formed (a) and finishing (b – orthogonal, c – parallel)

From intelligible regards, rough method of ball forming (Fig. 6a) assures its surface worst quality. Orthogonal finishing forming is next in sequence (Fig. 6b), in this regards finishing forming with parallel system of trace path of finishing and rough forming (Fig. 6c) is the most advantageous. It is proper to note, that last two ball models were formed not only by introduction of additional finishing forming operation but also by optimization of forming process, have on purpose by reflected ricochet jet minimization of additional eroded surface.

Used method of surface spatial forming is characterized by data presented in Tab. 2 [6] showing out comparison of qualitative effects. All this information, obtained thanks to measurements taking into account main SGP parameters exert, that introduction of finishing forming, especially with parallel path system, assures considerable improvement of quality of forming objects.

Tab. 2. Characteristics of different forming methods of ball model surface quality

Type of sphere model forming	Rough forming	Finishing forming		Relative quality bettering after forming	
		orthogonal	parallel	orthogonal	parallel
Amplitude parameters	*[mm]*	*[mm]*	*[mm]*	*[%]*	*[%]*
Sa (arithmetic mean of the deviations from the mean)	0,309	0,175	0,152	43,37	50,81
Sq (quadratic mean of the deviations from the mean)	0,417	0,223	0,196	46,52	53,00
Sp (highest peak of the surface)	1,7	1,04	0,551	38,82	67,59
Sv (deepest valley of the surface)	5,59	0,853	1,25	84,74	77,64
St (total height of the surface)	7,33	1,89	1,8	74,22	75,44
Sz (height of the 10 points of the surface)	2,53	1,17	1,35	53,75	46,64
Surface and volume parameters	*[mm^3/mm^2]*	*[mm^3/mm^2]*	*[mm^3/mm^2]*	*[%]*	*[%]*
Smmr (average material volume)	5,59	0,853	1,25	84,74	77,64
Smvr (average void volume)	1,74	1,04	0,551	40,23	68,33
Spatial parameters	*[pks/mm^2]*	*[pks/mm^2]*	*[pks/mm^2]*	*[%]*	*[%]*
SPc (density of peaks)	0,029	0,0838	0,0583	188,97	101,03
Sds (density of tops)	1,03	2,17	1,94	110,68	88,35
Sdr (developed surface)	49,1	10,4	8,97	78,82	81,73

5. BAS-RELIEF JETTING EXAMPLES

Spatial forming of rocky materials using high-pressure abrasive-water jet with utilization of virtual flat picture luminance processed here enables 3D objects reproduction in the form of bas-relief cut in cement plates. Example of that can be general view of such plate presented in Fig. 7 as well as some chosen details shown in Fig. 8 - Fig. 9 [6,7].

Basing on carried research it was established that application of sand-quartz provides high forming efficiency, however processed surface obtains relatively considerable roughness. Usage of fine-grained abrasives causes distinct drop of surface roughness. Therefore, it is necessary to carry finishing forming two-procedural, at first coarse-grained abrasive-water jet e.g. with sand-quartz grains, but next fine-grained abrasive-water jet.

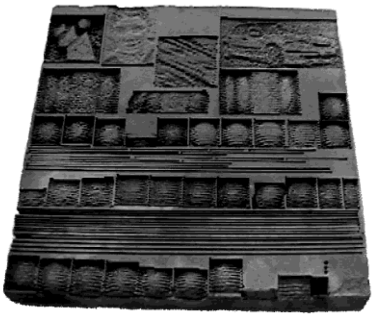

Fig. 7. Cement plate objects cut-out with high-pressure abrasive-water jet

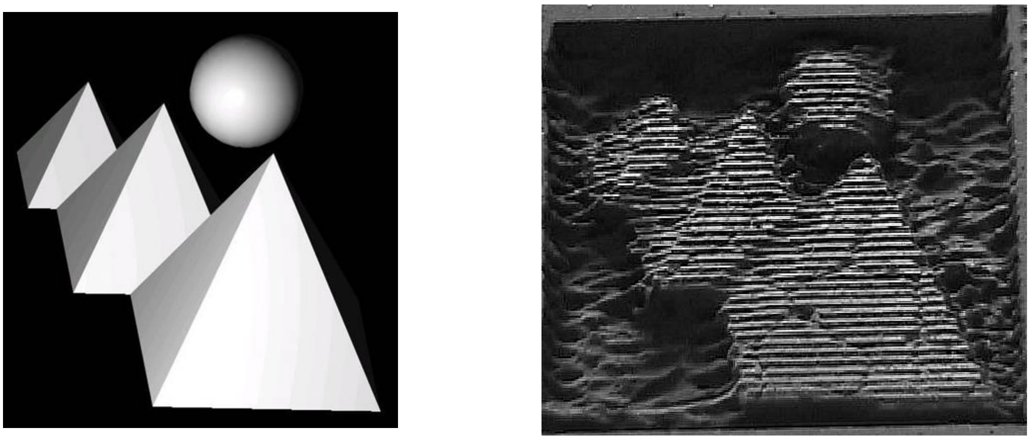

Fig. 8. The pyramids and sun relief created from capture of 3D ACIS objects

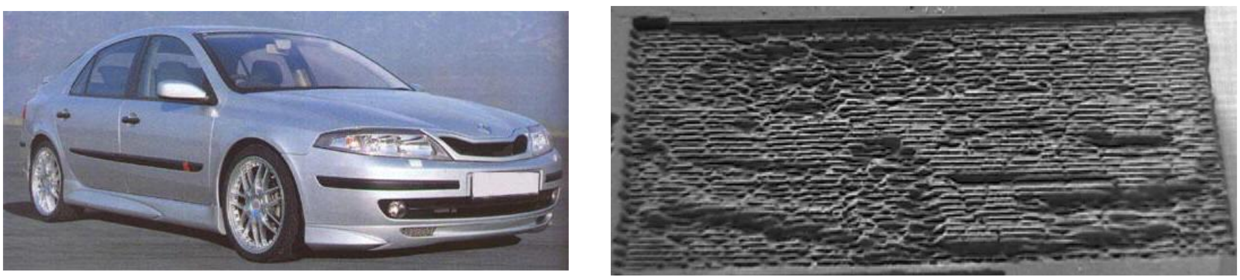

Fig. 9. The car relief created from photo of real object

6. CONCLUSION

Results of realized work let to establish many detailed procedural conclusions. Generalized form of those conclusions can be presented in the following form:

- Abrasive-water jetting application exclusively based on model *f(g),* without dynamic control of material eroding depth allows for good quasi-real modeling of flat image objects.
- Material model optimization *f(g, δ),* relying on its addiction from increase or decrease of processed points corrects at a great extent readability of form of object at simultaneous decrease of amplitude parameters.
- Algorithm optimization on rough and finishing dividing process decreases at a great extent amplitude parameters and improves readability of form of modeled object.
- Applications of such forming method include mainly constructions, especially rocky materials, for ornament or facade bas-relief, balustrade, decorative plates etc. decoration. After introducing finishing improvement operations such processing can have also application in many different branches of industries as well as be as high-speed forming of foundry matrix and forms.

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