KAUNAS UNIVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING AND DESIGN

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Analysis of the excitation influence on quality of thermally replicated periodical microstructure

Master's Degree Final Project

Supervisor

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KTU, Lithuania.

KAUNAS, 2017

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MECHANICAL ENGINEERING (621H30001)

Supervisor

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KAUNAS, 2017

KAUNAS UNIVERSITY OF TECHNOLOGY

Mechanical Engineering and Design

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Mechanical Engineering, 621H30001

(Title of study program, code)

"Analysis of the excitation influence on quality of thermally replicated periodical microstructure"

Final project

DECLARATION OF ACADEMIC INTEGRITY

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MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study program MECHANICAL ENGINEERING - 621H30001

Approved by the Dean's Order No. V25-11-20 of December 8, 2016 y

Assigned to the student Rajesh Daruru

(Name, Surname

1. Title of the Project

Analysis of the excitation influence on quality of thermally replicated periodical microstructure

2. Aim of the project

To investigate the quality of periodical micro structure replicated using square and noise excitations during hot imprint process

3. Tasks of the project

- To do literature review and to choose experimental techniques for periodical microstructures hot imprint and analysis.
- To determine the optical imprint technological parameters pressure and temperature for the hot mechanical imprint process.
- To determine the influence of square and noise type excitation in to quality of thermally replicated periodical microstructure.

4. Specific Requirements

Conducting the final experimental project thesis according to KTU regulations and requirements.

5. This task assignment is an integral part of the final project

6. Project submission deadline: 2017 January 11th.

Task Assignment received ______________________ ______________________

(*Name, Surname of the Student*) (*Signature, date*)

Supervisor ______________________ ______________________

(*Position, Name, Surname*) (*Signature, date*

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Study field and area: Technological science, Mechanical engineering

keywords: Mechanical hot imprint, Periodical microstructure, diffraction, vibroactive pad, square and noise wave frequency;

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SUMMARY

sensors are widely used in bio-sensing of processes, such as analysis of concentration of micro particles in biological environment. diffraction grating is one of the main optical components of a sensor and it helps in splitting the light into several beams. diffraction grating is produced by mechanical hot imprint method. in this research study quality of microstructures, created by square wave and noise excitation are analysed and compared.

Two types of setups are arranged to determine the optical imprint technical parameters and quality of thermally replicated periodic microstructure. to analyze the quality of microstructure. vibro-active pad, whose fundament is piezoelectric element, is used to generate high frequency longitudinal vibrations. at the same temperature, pressure and time modes, two types of microstructures are created by square and noise wave excitations. laser and photodiode bpw-34 are used to analyze the diffraction measurements. Square and noise waves are generated at a frequency of 8.460 KHz and an amplitude of 5V for evaluating the quality of periodical microstructure. Optical imprint technical parameters and quality of thermally replicated microstructure are defined using red and green lasers at different temperatures of 148℃, 152℃ and pressures ranging from 1 to 5 bar. In the end of the paper replicated microstructure are experimentally analysed using square and noise wave frequency. Furthermore, this method does not require expensive or complex developments of the experimental setup and could be applied in most equipment's of thermal imprint.

Rajesh Daruru, Terminiu būdu su išoriniu žadinimu antrinamų periodinių mikrostruktūrų kokybės tyrimas, Magistro baigiamasis darbas. Technologijos mokslai, Mechanikos inžinerija / Vadovas prof. dr. Arvydas palevicius; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

aktiniai žodžiai: Mechaninė karšto Atspaudas, periodinis Mikrostruktūros, difrakcijos, vibroaction trinkelėmis, kvadratinės ir triukšmo bangų dažnio;

Kaunas, 2017. 50 p.

SANTRAUKA

Jutikliai yra plačiai naudojami biologiniuose jutimo procesuose, pavyzdžiui mikro dalelių koncentracijos biologinėje aplinkos analizėje. Difrakcinė gardelė yra vienas iš pagrindinių jutiklio optinių komponentų, ji išskaido šviesą į keletą pluoštų. Difrakcinė gardelė yra gaminama terminio spaudimo metodu. Šiame darbe yra analizuojama ir lyginama mikrostruktūros kokybė, kuri pagaminta naudojant aikštė ir triukšmas žadinimą proceso metu.

Vibropadas, kurio pagrindas yra pjezoelektrinis elementas, naudojamas generuoti aukšto dažnio virpesius. Esant tai pačiai temperatūrai, slėgio ir laiko režimams, bet naudojant kvadratinį ir triukšminį žadinimą yra sukurtos dviejų tipų mikrostruktūros. Lazeris ir fotodiodas BPW-34 yra naudojami difrakcijos efektyvumo matavimams. Kvadratinė ir triukšminė bangos yra generuojamos esant 8.46 kHz dažniui ir 5V amplitudei tam, kad įvertinti periodinės mikrostruktūros kokybę. Optinio įspaudo techniniai parametrai ir termiškai atkartotos mikrostruktūros kokybė yra nustatomi naudojant raudonos ir žalios šviesos lazerius, esant skirtingoms temperatūroms 148 ℃, 152 ℃ bei slėgiams nuo 1 iki 5 bar. Darbo pabaigoje atkartota mikrostruktūra yra eksperimentiškai analizuojama atsižvelgiant į naudotą kvadratinį ar triukšminį žadinimą. Be to šis metodas nereikalauja brangios ar sudėtingos įrangos ir gali būti taikomas daugeliui terminio spaudimo įrenginių.

CONTENT

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INTRODUCTION:

Nowadays the scientific equipment is used in Nano and micro level of measurements, it's mainly consist of micromechanical system. In future micromechanical system depends on up on the periodical microstructure such type of periodical microstructure is used in laser, sensors, holography, etc.

In periodical microstructure construct the narrow grooves it separated the space between the level of propagating light wavelength. The help of polychromatic propagating light can be separated periodical microstructure compounds. In furthermore depends on components of microstructure propagating light can be reflected or transmitted.

By mentioning the Nano levels, it’s very small materials and quality of periodical microstructure providing a good efficiency of the experiment results. To achieve the good quality of replicated periodical microstructure and its processing regimes maintain the manufacturing of microstructure.

The aim master thesis is to investigate the quality of periodical microstructure replicated using square wave and noise excitations during hot imprint process.

Following tasks were assigned and then achieve the formulated aim:

- To do a literature review and to choose experimental techniques for periodical microstructures hot imprint and analysis.
- To determine the optical imprint technological parameters pressure and temperature for the hot mechanical imprint process.
- To determine the influence of square and noise type excitation into quality of thermally replicated periodical microstructure.

1 LITERATURE REVIEW:

1.1 Periodical microstructure:

In the first periodical microstructure David Rittenhouse made in 1785[1], American astronomer. It must have reported the microstructure half inch wide. It was very small microstructure but it is the beginning of the invention. Until 1785 changes the manufacturing ways of periodical microstructure, but the whole concept was left unchanged. In that microstructure constructed the narrow grooves between the space and the level of propagating light wavelength (Fig. 1.1.).

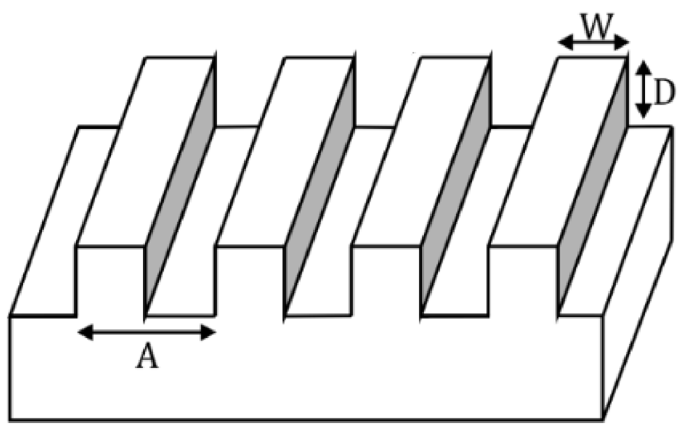

Figure 1. Periodical microstructure (A-period, W- half period, D- depth) [1]

The periodical microstructure can be formed two ways: reflection and transmission. In this reflection, periodical microstructure transmits the interference of propagating light waves in different optical displacement. In periodical microstructure divided into small group geometry: one dimensional, two dimensional, three dimensional. So, two-D and three-D microstructure differ from 1-D phase ability changes [2,3].

Create an efficient periodical microstructure, which would show good and precise results when using it, it is a very good production quality. The resulting problem in the production quality, like non-periodical structure. Impurities, fractures, and other obstacles may arise.

Selection of materials fabrication of periodical microstructure its ability to know the behavior of working process, the substrate (Fig. 2.) small and medium-sized microstructure selected from and lead borosilicate crown glass (BK-7), fused silica. In these low expansion material or thermoplastic material, the large periodical microstructure can be considered as a standard and low expansion materials, thermoplastic material involved as well as annealed borosilicate crown glass [4].

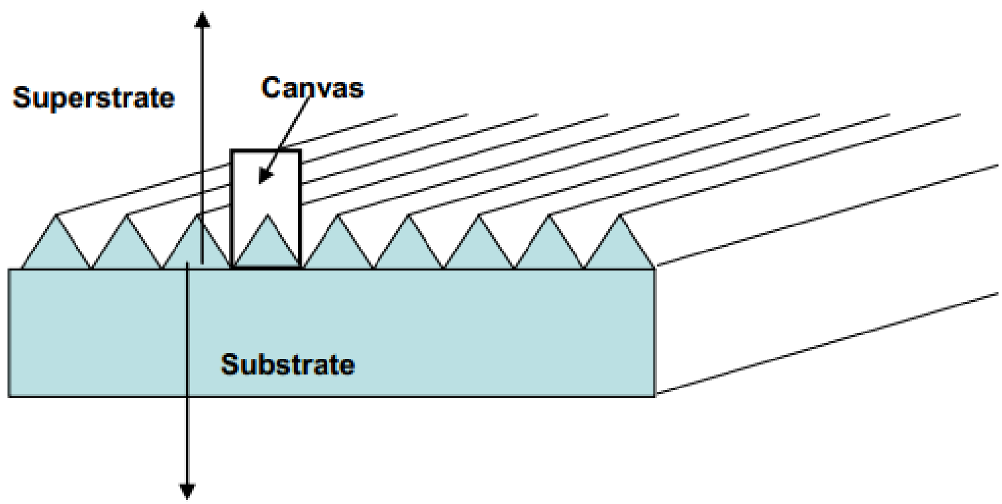

Figure 2. Periodical microstructure geometry [5]

Quality problems are the main concern of scientists working the periodical microstructures, each replication process has its own advantages and disadvantages, manufacturing of periodical microstructure depends on where it's used microstructure. These periodical microstructures are widely used in lasers, in microelements used to decrease wavelength, change the wavelength dissipation to control the pulse for the laser.

1.2 Methods of replication periodical microstructures

Periodical microstructure fabrication can be using different methods: ultraviolet embossing, injection molding, ultransonic hot embossing mechanical hot imprint method. Well, know technological processes ultraviolet embossing, injection molding used in a long time for manufacturing microreplication. In the mechanical hot imprint method is well suitable for medium and small series of microcomponents and then low cost of replication [5]

Ultraviolet (UV) embossing is used for mass production of microstructures. It consists of two steps:

1. The coating process;
2. The imprinting-curing process.

A flexible resin, such as polycarbonate or polyester is unwound from a bale. It is then coated with liquid phase UC curable resin, which is dried in the dryer. The flexible resin continues to roll to the embossing roller, which presses the replica of the master mold of needed microstructure at a constant pressure. A high-power UV light then is used to cure and harden the embossed resin (Fig. 1.3.) [6].

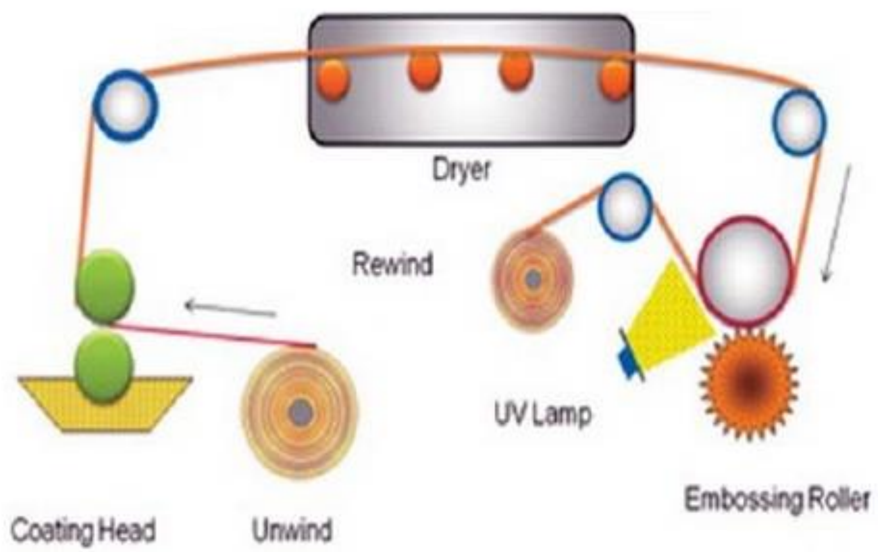

Figure 3. Ultraviolet embossing process [6]

Injection molding of microstructures is like injection molding used in manufacturing for producing parts for machines or packaging units. The difference for microstructures is that it is done in the micro level, where the amount of injected material is very small and even the smallest impurity can cause defects in the final product.

The Ultrasonic method uses supersonic vibration energy to melt thermoplastic compound substrates for small pattern replication. The small-scale vibration of the horn causes repetitive deformation of the compound surface, which ends in heat generation because of deformation more over as friction.

Because the high-frequency supersonic vibration repeats, the temperature of the compound will increase till its softens. Therefore, the small patterns carven on the horn or mold surface will simply be replicated on the softened substrate. Figure(a) Its could be a schematic of the supersonic press system an supersonic power provide, a gas pressing unit, an supersonic horn, and a measuring unit for load management [24].

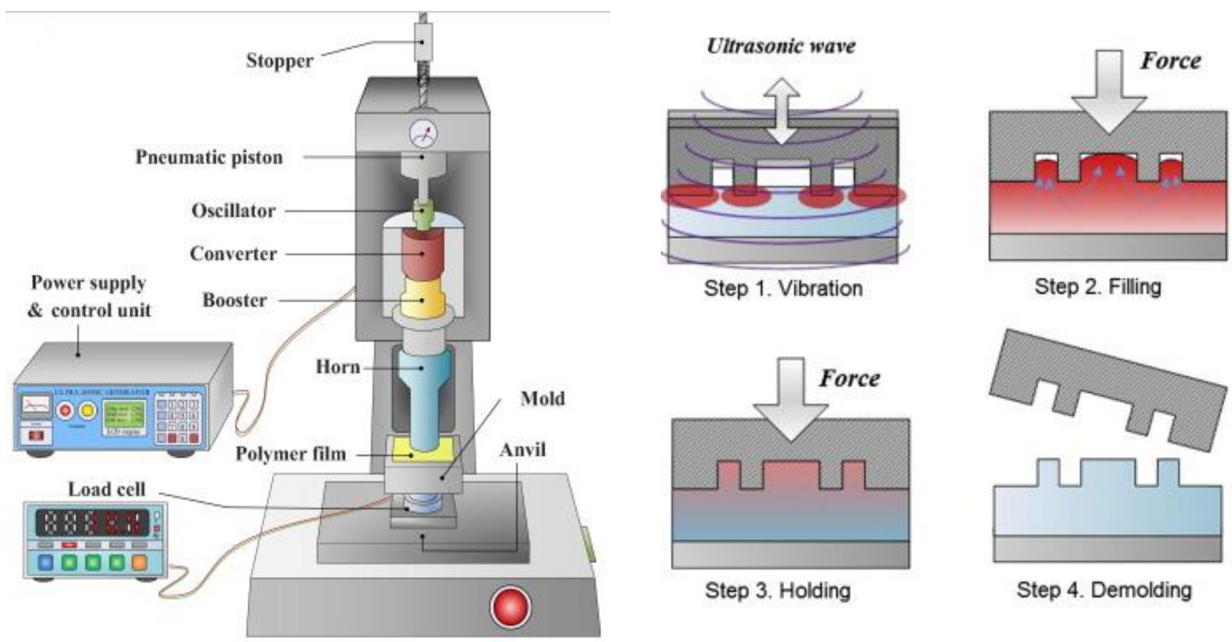

Figure 4. Ultrasonic imprinting system: (a) schematic configuration, and (b) stepwise description

The Ultrasonic method follows four steps, as illustrated in Fig(b), the primary step is that the vibration step wherever associate degree unhearable horn pushes a polymer chemical compound substrate repeatedly mistreatment unhearable ultrasonic vibration. Next step is that the filling step, during which deformation heat softens the polymer chemical compound surface enough that small cavities on the horn surface area unit stuffed with melted chemical compound.

once this filling step, a holding force is maintained for several seconds to improve replication by permitting the chemical compound surface to completely solidify. Finally, the horn recedes and the replicated substrate is ejected from the mildew. Among these steps, the most concern of this study is that the vibration step, throughout that the polymer chemical compound surface is heated regionally by unhearable ultrasonic vibration.

During the injection molding process, the preheated material to its melting temperature is injected right before the molds press against each other. The material is still heated with the heater to maintain its temperature during the period of clamping. After clamping, the heater is shut down and the mold and material are cooled down. The cycle times in the range of minutes [7]. In the Fig. 1.4, the injection mold is shown with its respective parts.

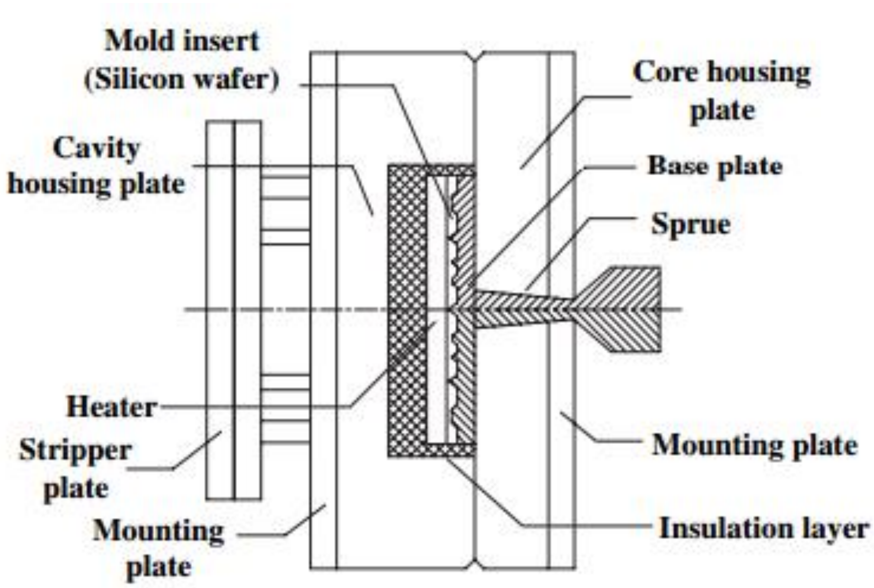

Figure 5. Injection mold [8]

In mechanical hot imprint process mainly divided three steps preheating, imprinting, demolding. In these preheating step, polycarbonate is heated up to chosen temperature, this temperature glass transition temperature of polycarbonate [9].

The temperature reaches rubbery state of polymer that polymer leaves the brittle state and its start reversibly and irreversibly deformed under the mechanical stress. In imprinting gives the pressure and temperature, the contact force between mold and polycarbonate in that polycarbonate plastic deformation formed. Demolding, in that demolding act as polycarbonate, is cooled down at ambient temperature [10].

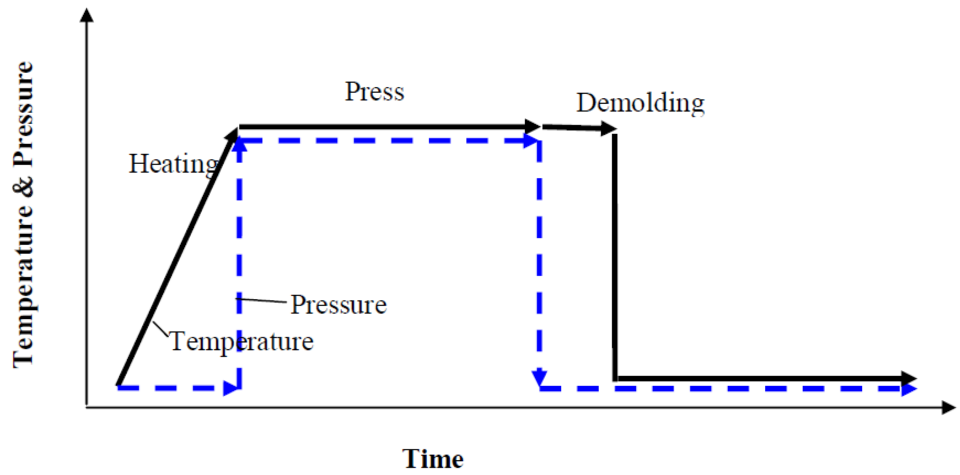

Figure 6. Schematize diagram of mechanical hot imprint process [9]

1.3 Measuring methods of periodical microstructure:

In these periodical microstructure analyses in two different types one is direct and another one is indirect [11], indirect analysis is situated with scanning electron microscope (SEM) and atomic force microscope (AFM), other equipment and optical microscope determine the surface pattern parameters [12]. The indirect analysis is applying diffractive and interfering measuring methods. Using the laser, it is possible to study periodical microstructure's parameters and indirectly determine the geometrical parameters of surface pattern.

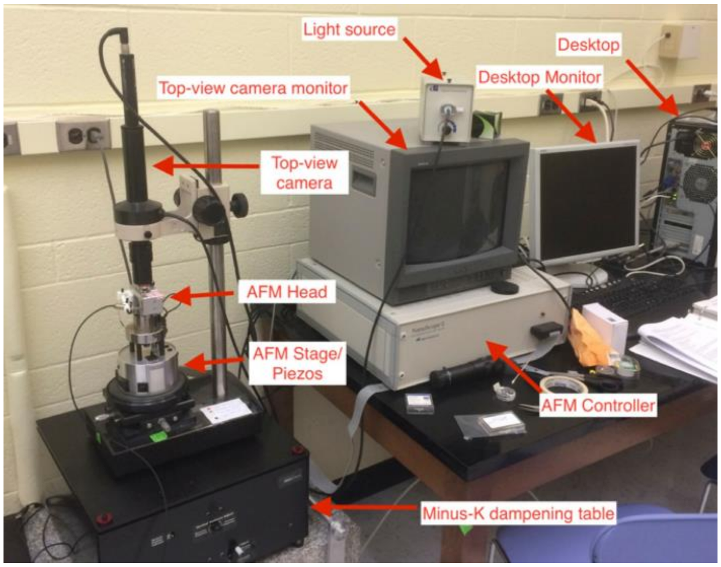

Figure 7. Schematic diagram of Atomic force microscopic

By using the scanning electron microscope, it’s possible to measure the surface pattern parameters of periodical microstructure even in the near-infrared region of visible light [13]. However, because of high costs of specimen’s preparation and small size, the price of this analysis reaches high levels. Also, the specimen can be damaged, what can cause failures in the continuous usage of the periodical microstructure.

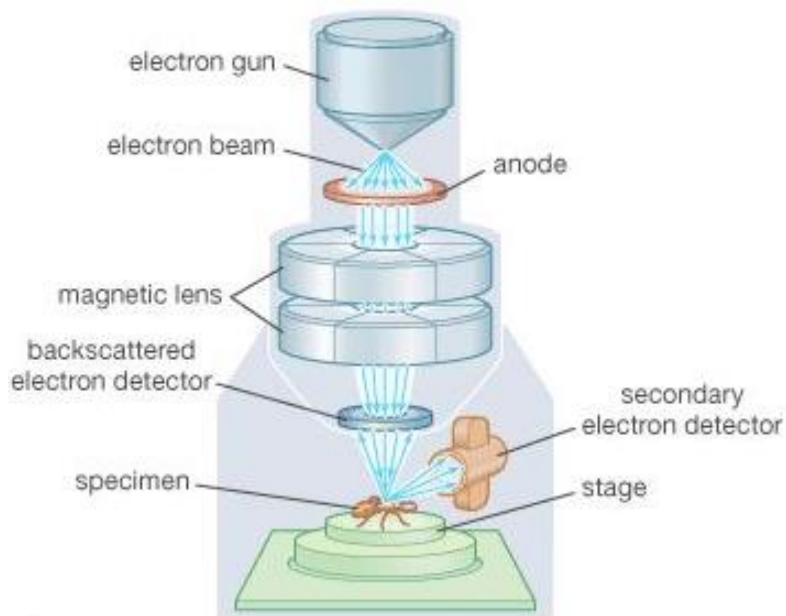

Figure 8. Schematic diagram of scanning election microscopic

The diffraction efficiency values optical parameters of a periodical microstructure. Two values are measured: absolute efficiency or relative efficiency. The energy flow of monochromatic light diffracted into the order being measured efficiency, the energy flow of incident light is relative either (absolute efficiency) or the energy flow of specular reflection coated with a polished mirror substrate the same material (relative efficiency) [1]. To fully understand analyzed objects, diffraction efficiency and diffraction order distribution measurements are done Fig.1.6.

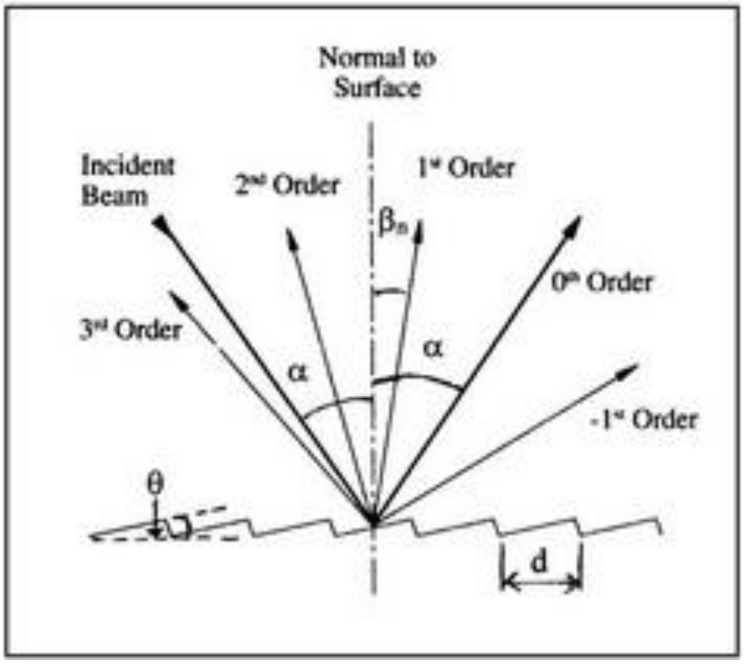

Figure 9. Periodical microstructure's diffracted orders [14]

1.4 Formulation of research objectives:

Previous analysis the worldwide scientific literature, has been written by researchers from Kaunas University of Technology, important parameters of thermal embossing method area unit the pressure, the pressing time and therefore the temperature. countless scientific studies were done by analyzing every parameter severally.

The biggest concern now could be however these parameters act once introduced to high frequency vibrations and the way the surface of a master periodical microstructure is going to be replicated once their area unit totally different combination of important parameters. The aim of Master thesis is to research the impact of operating regimes into quality of periodic microstructure's. With this aim, many objectives were formulated:

- To do a literature review and to choose experimental techniques for periodical microstructures hot imprint and analysis.
- To determine the optical imprint technological parameters pressure and temperature for the hot mechanical imprint process.
- To determine the influence of square and noise type excitation into quality of thermally replicated periodical microstructure

1.5 Grating:

A grating is a spaced basically identical, parallel, elongated component. Gratings sometimes accommodate one set of elongated components however, will accommodate two sets, during which case the second set is typically perpendicular to the primary. Once the second sets square measure perpendicular, this is often additionally called a grid [15].

The grating can even be available four feet (1,219 mm) or two feet (610 mm) and eight feet (2,438 mm) panels that square measure typically used for decks on bridges, footbridges, and catwalks. The grating is an optical phenomenon grating a reflective or clear optical element on that there square measure several fine, parallel, equally spaced grooves [15].

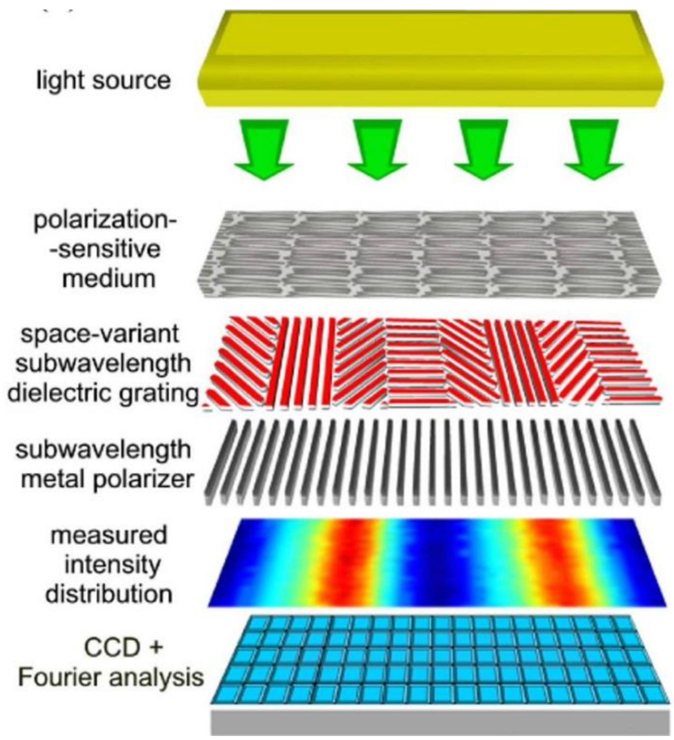

Figure 10. Novel method for real-time polarization measurement by use of a discrete space-variant subwavelength dielectric grating [15]

1.6 General application of diffraction grating:

In the diffraction grating, optical components used to separate polychromatic light into constituent optical frequencies. The simple gratings consist of the glass substrate the series of parallel, equispaced lines form surface of the glass [16].

Diffraction grating is often used in:

- Monochromators
- Spectrometers

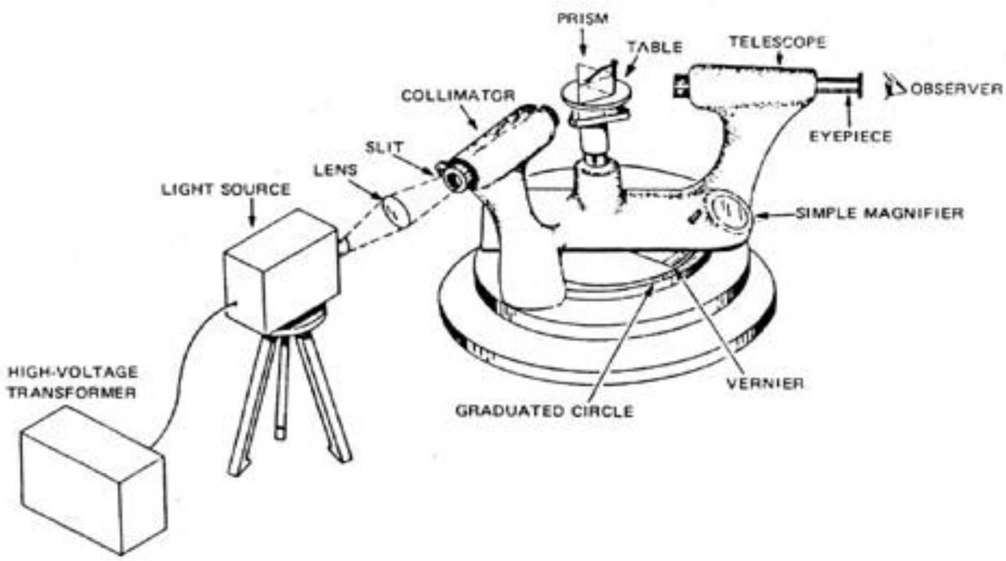

Figure 11. Schematic diagram of spectrometer

- Wavelength division multiplexing devices

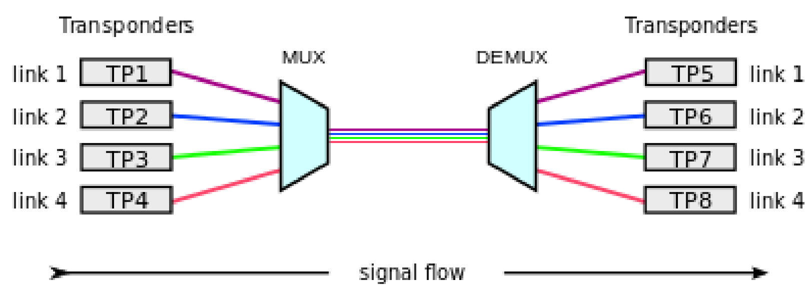

Figure 12. Schematic wavelength division multiplexing

- Optical pulse compressing devices
- Many other optical instruments
- Diverse fields as laser optics, spectroscopy, metrology, and colorimetry.

Here it's important to know that grating equation it could be easy for understanding the way of calculation and the method of using diffraction grating. So, that grating equation is:

$$d\times(\sin a \pm \sin b) = ml$$

Where:

a- Angle of incidence
b- Angle of diffraction

d-Distance between adjacent grooves

m- Order integers 1,2,3,4 etc.

l- Wavelength of the incident beam

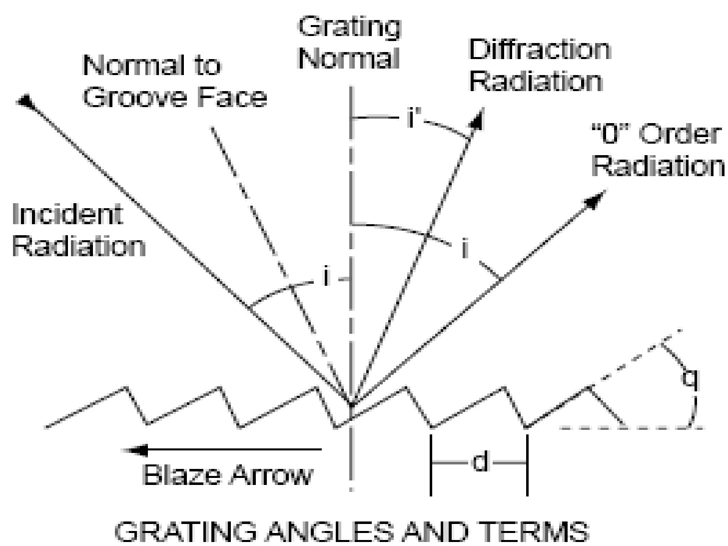

Figure 13. Grating Equation [16]

1.7 Diffraction orders:

Since light-weight completely different of various wavelengths are diffracted at different angles, every order to drawn into a spectrum. Every spectrum consists of monochromatic pictures of the. Incident bundle, with the blue image nearer to the central axis, but if monochromatic light-weight is incident on the grating, many output beams are going to be generated, this sort of device are often used for the generation of multiple lasers (i.e. a beam splitter)

The number of orders that may be created by a given grating is proscribed by the grating constant as a result cannot exceed ninety degrees. the best order is given by d/l. Consequently, a rough grating manufactures several orders whereas a fine grating might produce only 1 or 2[18].

1.8 Example of diffraction grating:

Ordinary ironed CD and video disc media area unit every-day samples of optical phenomenon gratings and may be want to demonstrate the impact by reflective daylight off them onto a white wall. This can be a facet impact of their manufacture, together surface of a CD has several little pits within the plastic, organized at intervals concentric rings; that surface incorporates a skinny layer of metal applied to create the pits additional visible.

The structure of a video disc is optically similar, though it should have quite one cavities surface, and everyone cavities surfaces area unit within the disc. in an exceedingly commonplace ironed vinyl record once viewed from an occasional angle perpendicular to the grooves, the same however less outlined impact to it seen in an exceedingly CD/DVD [17].

This can be thanks to viewing angle (less than the incidence angle of reflection of the black vinyl) and therefore the path of the sunshine being mirrored thanks to this being modified by the grooves, going away a rainbow relief pattern behind. The imaging device of a camera incorporates a fine pattern which may turn out an optical phenomenon physical object on the image.

Figure 14.The grooves of a compact disc can act as a grating and produce iridescent reflections[18]

Diffraction gratings are a gift in nature. for instance, the colors of peacock feathers, shell, butterfly wings, and a few alternative insects square measure caused by terribly fine regular structures that split light-weight, rending it into its element colors.

A photographic slide with pattern of black lines forms a straightforward grating. For sensible applications, gratings typically have grooves or rulings on their surface instead of dark lines. Such gratings are often either clear or reflective [19]. Gratings that modulate the part instead of the amplitude of the incident light-weight are made, often victimization optics.

2 Experimental and modeling equipment

2.1 Polycarbonate used for replication periodical microstructure:

In the replication of periodical microstructures and application of polycarbonate was analyzed by Janusas G. and Narijauskaite B. in 2013. It's declared that polycarbonate could be an appropriate material for periodical microstructure's replication attributable to its physical properties, such as [20].

- Strength
- Ability withstand scratches
- Easily cleaned
- Usability at high temperatures

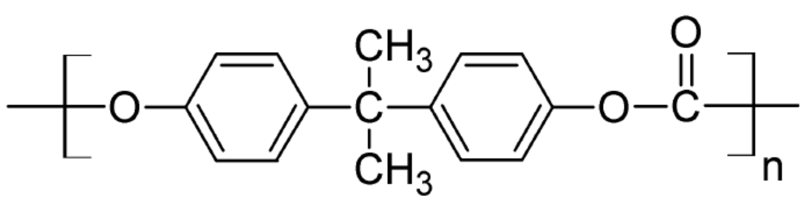

Figure 15. Chemical composition of polycarbonate

There are two domine processes involved making the product of polycarbonate: Extrusion, Injection moulding. The compound soften is unceasingly ironed through associate degree passage referred to as a "die", which supplies the melted compound its final form. when passing through the die the soften cools apace and solidifies thus maintaining the given form. This method makes it doable to make infinitely long pipes, profiles or sheets.

The hot compound soften is ironed into a mould. The mould is then cooled, and therefore the hot compound solidifies seizing all the characteristics of the mould. This method is employed to form single finish product, like housings, plates, bottles, and plenty of alternative applications.

2.2 Properties of polycarbonates:

In this topic, I explain the thermal, chemical, and physical properties of polycarbonate are shown in table 2.1- Table 2.2- Table 2.3.

Table 1. Thermal properties of polycarbonate

Melting temperature	267℃
Glass transition temperature	150℃
Heat deflection temperature-10 kN	145℃
Heat deflection temperature0.45 Mpa	140℃
Heat deflection temperature – 1.8 Mpa	128-138℃
Upper working temperature	115-130℃
Lower working temperature	-40℃
Linear thermal expansion coefficient	65-70×10-6/K
Specific heat capacity	1.2-1.3 kJ/(kg·K)
Thermal conductivity 23℃	0.19-0.22 W/(m·K)

Table 2. Chemical properties of polycarbonate

Young’s modulus	2.0-2.4 Gpa
Tensile strength	55-75 Mpa
Compressive strength	>80 Mpa
Poisson’s ratio	0.37
Coefficient of friction	0.31

Table 3. Physical properties of polycarbonate

Density	1.20-1.22 g/cm3
Refractive index	1.584-1.586
Water absorption – Equilibrium	0.16-0.35%
Water absorption – Oveer24 hours	0.1%
Light transmittance	88%

2.3 Mechanical hot imprint setup and monitoring:

The mechanical hot imprint method may be a complicated technological operation, because of materials state changes. The mechanical hot imprint method is performed with a mechanical press (Fig.2.2.). It consists of hydraulic hold, gage of pressure, mold horn, controlled stage, thermometer, dynamometer its control the temperature, time, and pressure. Its main parameters are measured in below. To extend the standard of high-frequency oscillation of replicated microstructure, performing the replication process [21].

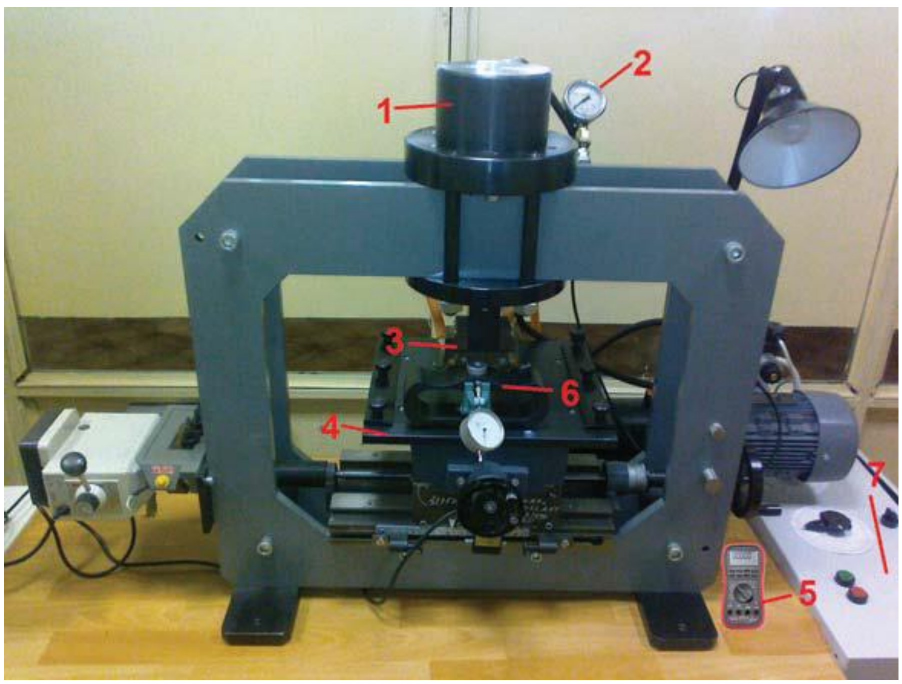

Figure 16. Hot imprint device: hydraulic hold (1), gage of pressure (2), mold horn (3), controlled stage (4), thermometer (5), dynamometer (6), and control block of temperature, time, and pressure (7).

The diagram of supersonic or ultrasonic thermal embossing is bestowed in Fig. 2. first, the moving plate (1) with the master mold (2) is preheated and maintained to own the selected temperature. The heated plate then is captive to the polycarbonate (3). By pressing the rigid mold with the specified pattern, a negative pattern is achieved. At the constant moment, the vibroactive pad (4), that relies on the bottom of the tool (5) starts to come up with high-frequency excitations [21].

Table 4. Specification of mechanical hot imprint setup

Range of temperature	20-200℃
Range of pressure	0–106 N/m2
Horn measurement	20mm-200mm

In mechanical hot imprint process mainly divided three steps preheating, imprinting, demolding. In these preheating step, polycarbonate is heated up to chosen temperature, this temperature glass transition temperature of polycarbonate [9]. The temperature reaches rubbery state of polymer that polymer leaves the brittle state and its start reversibly and irreversibly deformed under the mechanical stress. In imprinting gives the temperature and pressure, the contact force between mold and polycarbonate in that polycarbonate plastic deformation formed. Demolding, in that demolding act as polycarbonate, is cooled down at ambient temperature [10]

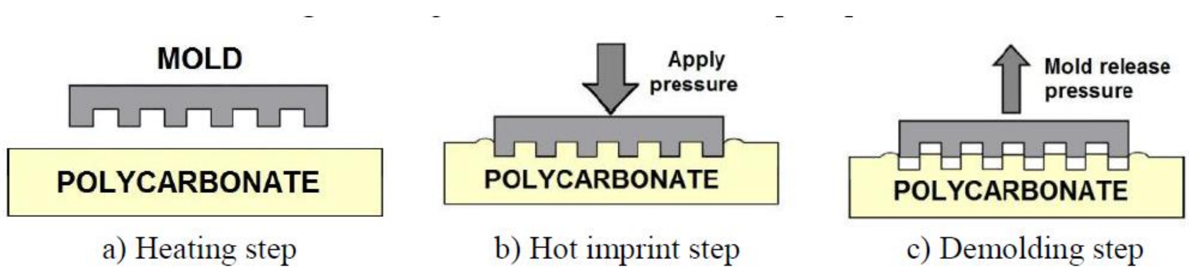

Figure 17. Schematize steps of mechanical hot embossing process [9]

2.4 Vibroactive pad:

In mechanical hot imprint process provides a low-quality periodical microstructure and its eliminate these faults high-frequency vibration send to through the vibrating pad is introduced in the replication process [22].

In Kaunas university of technology team constructed the vibrating pad to excite the high-frequency vibrations into the polycarbonate, to increase the quality of replicated periodical microstructures. These vibrating pads constricting of stainless steel and the rings of piezoelectric material, these piezoelectric material is excited to produce the vibrational response, a piezoelectric element selected was PZT-4. Its properties are shown in table 2.4.

In Kaunas university of technology team and scientists worldwide it was shown that the high-frequency vibrations improve the quality of replicated periodical microstructure. The aim of this master thesis is to analyze how different process replicated periodical microstructure with the help of high-frequency vibrations improve the quality.

In the experiment, both Square and noise frequency vibration were used. They excited two forms of vibrations. All other process parameters can be seen in the Table2.5.

Table 5. Properties of PZT-4 material [22]

General	
Density (10^3 kg/m^3)	7.5
Curie temperature (K)	601
Elastic Constants	
c_{11}^E (GPa)	139
c_{33}^E (GPa)	115
c_{12}^E (GPa)	77.8
c_{13}^E (GPa)	74.3
c_{44}^E (GPa)	25.6
c_{66}^E (GPa)	30.6
Piezoelectric constants	
e_{31} (C/m^2)	-5.2
e_{33} (C/m^2)	15.1
e_{15} (C/m^2)	12.7
Dielectric constants	
ε_{11}^T (10^{-9} F/m)	6.461
ε_{33}^T (10^{-9} F/m)	5.620

In these created vibroactive pad was selected to cylinder geometry with dimensions as following: 40 mm external diameter top surface same as bottom; 36 mm internal diameterof ring and 5 mm thickness of PZT ring(Figure 13). It was made of stainless steel.

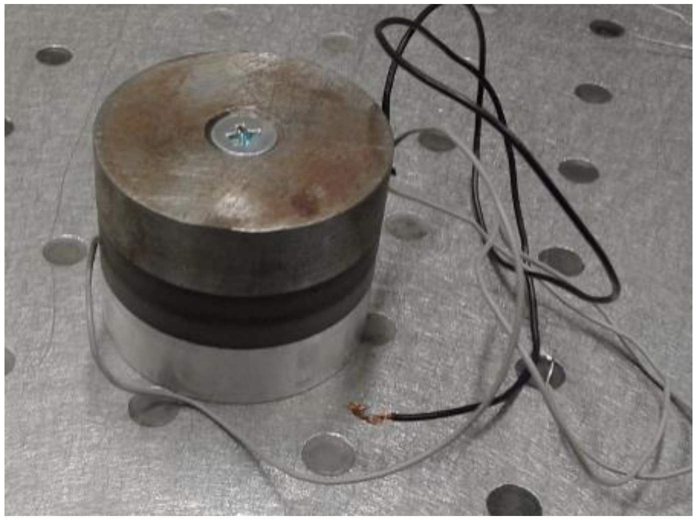

Figure 18. Schematic diagram of vibroactive pad

Table 6. Periodical microstructure replication process parameters

Vibrations	Pressu	Temperatu	Tin
Square (f=8.460 kHz; U=5.000 V) Noise (f=8.460 kHz; U=5.000 V)	0.1 Mpa 0.2 Mpa 0.3 Mpa 0.4 Mpa 0.5 Mpa	148 °C 152°C	10 s 10 s 10 s 10 s 10 s

In these frequency vibrating generators send the frequency through the vibroactive pad and the pad is vibrating for pressing the polycarbonate as show in frequency in above table.

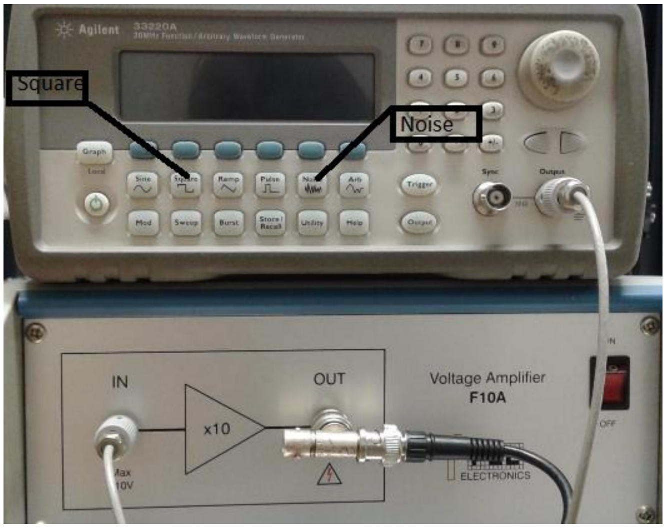

Figure 19. Schematic diagram of vibration frequency generator

2.5 Diffractor meter setup and monitoring:

In these investigation setups for diffractor meter used to determine the quality of thermally replicated periodical microstructure with the help of three major parts photodiode, sample, and ammeter. In these we are two laser wavelength uses (λ = 633 nm and λ = 533 nm) and photodiode BPW-34 were used to measure the quality of diffraction efficiency.

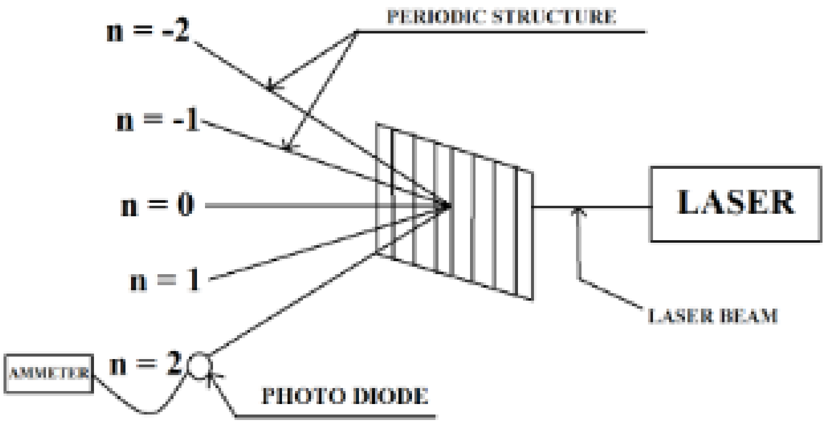

Figure 20. Optical scheme of diffractometer

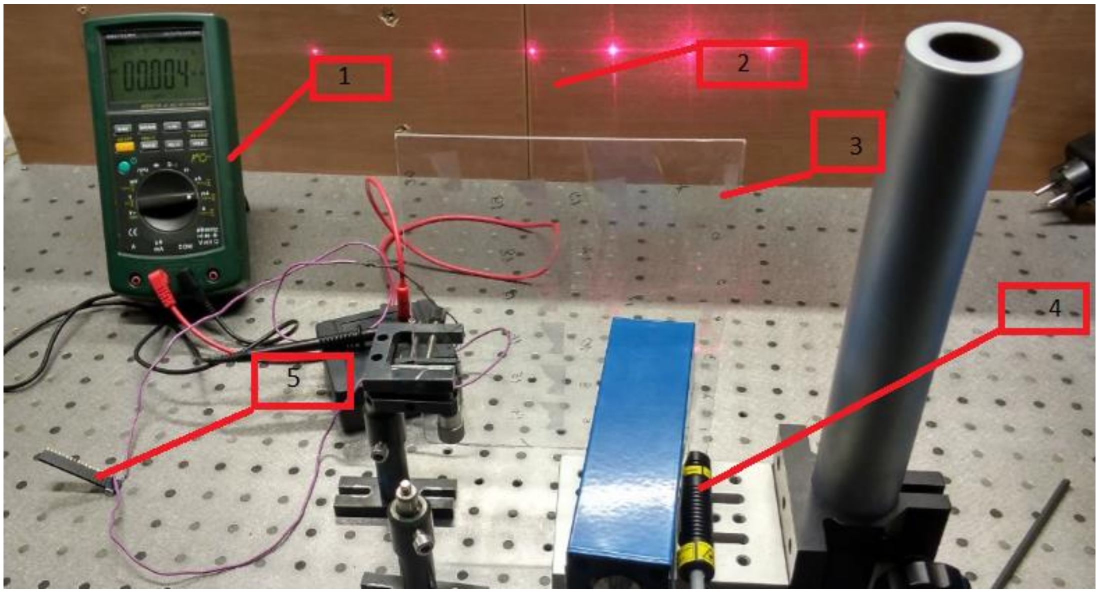

Figure 21. Measurement of diffraction efficiency: 1 – Ammeter, 2 – Distribution of diffraction maxima, 3 – Sample, 4 – Laser light, 5 - Photodiode, Connected to ammeter

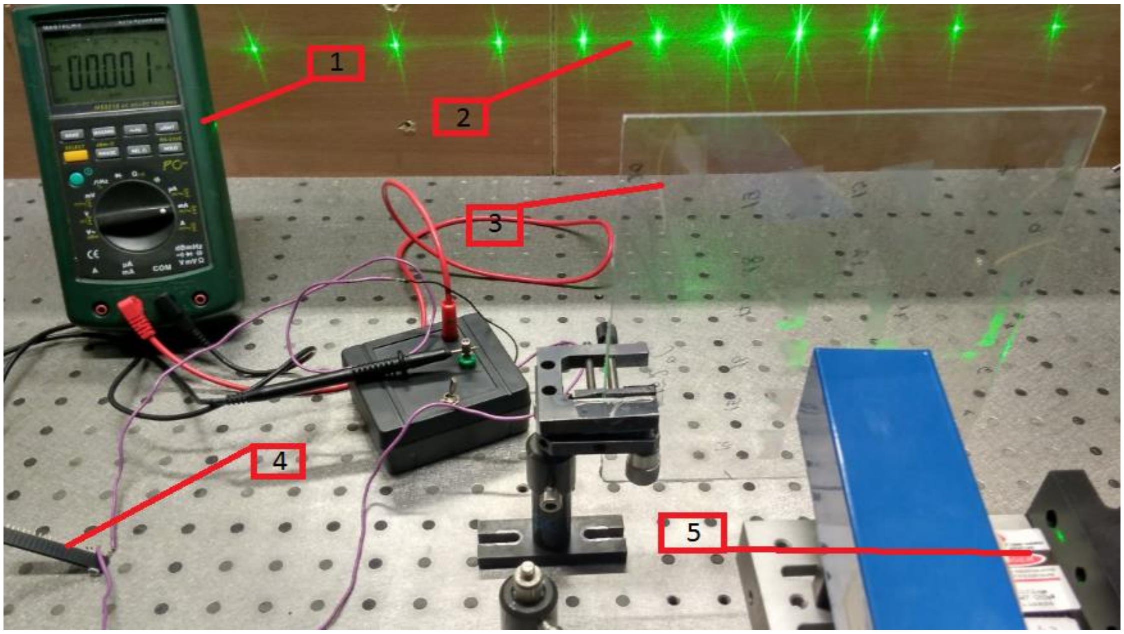

Figure 22. Measurement of diffraction efficiency: 1 – Ammeter, 2 – Distribution of diffraction maxima, 3 – Sample, 4 – Photodiode, connected to ammeter, 5 – Laser light

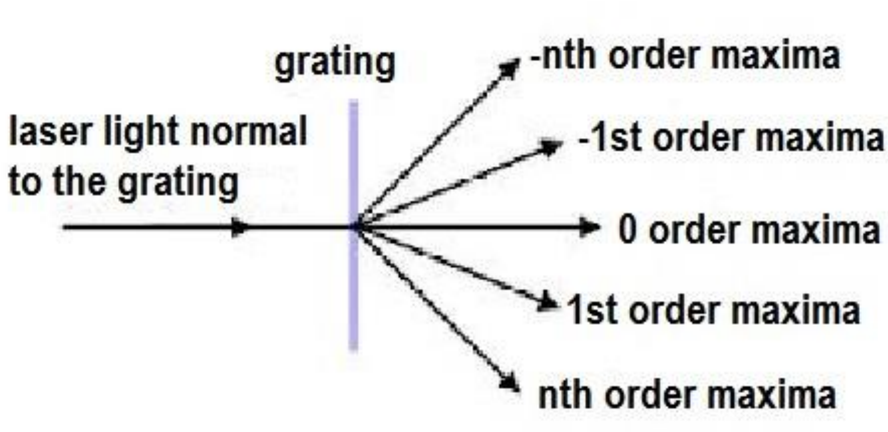

Figure 23. Simplified scheme of distribution of diffraction maxima

To eliminate material optical properties and, the relative diffraction efficiency RE is calculated by using following formulas: [9]

$$RE_i = \frac{I_i}{I}$$

$$I = \sum_i I_i$$

Here I_i - the intensity of diffraction maxima, I - the sum of all intensities of diffraction maxima, RE_i- relative diffraction efficiency.

The current passes through the photodiode, photodiode connected to the ammeter. The current is directly proportional to the number of light photons which strike the photodiode. The above equation sum of all current is calculated through the current and is divided from the sum of relative values of diffraction efficiency. In this practice, which determine the optical quality of grating +1 and -1 maxima. In these maxima, property is strongly applicable for various application. (23)

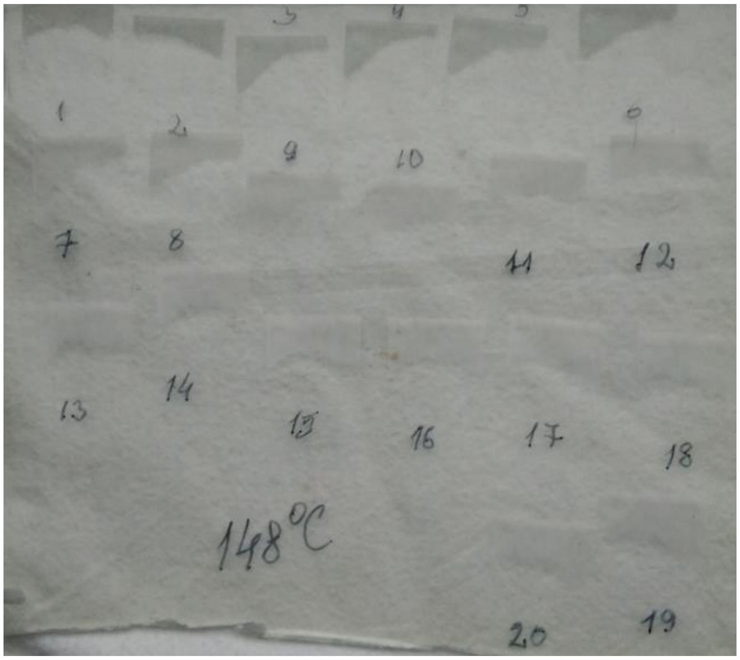

Figure 24. Specimen for polycarbonate temperature is 148℃

In these above amd below polycarbonate specimen made with different temperature 148 and 152, with different pressure 0.1 Mpa, 0.2 Mpa, 0.3 Mpa, 0.4 Mpa, 0.5 Mpa.by using vibroactive pad and mechanical hot imprint setup.

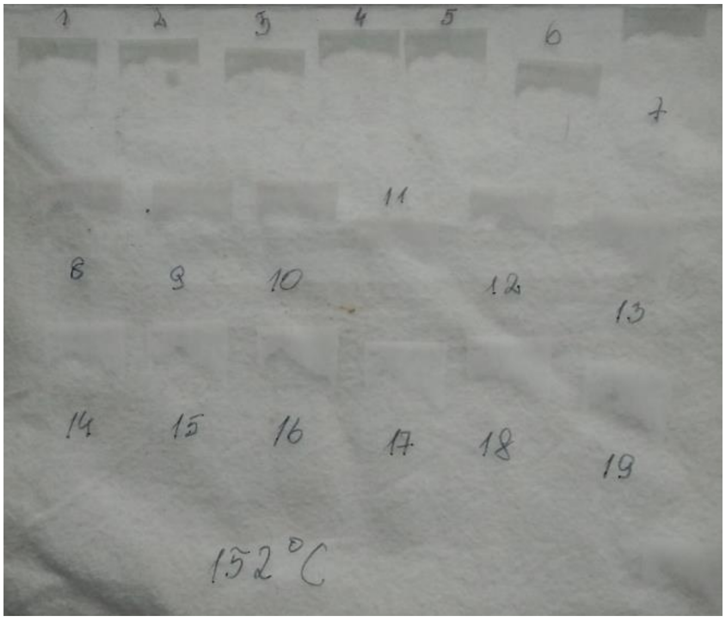

Figure 25. Specimen for polycarbonate temperature is 152℃

3 Results and discussion:

3.1 Investigation of optical parameters for pressure and temperature:

In these results, Check the optical imprint between the technological parameters pressure and temperature, with the stranded deviation by using different pressure 1 bar, 2 bar, 3 bar, 4 bar, 5 bar, Time is 10 seconds, temperature 148 and 152 and then here using square, noise frequency generator and red laser (λ = 633 nm)

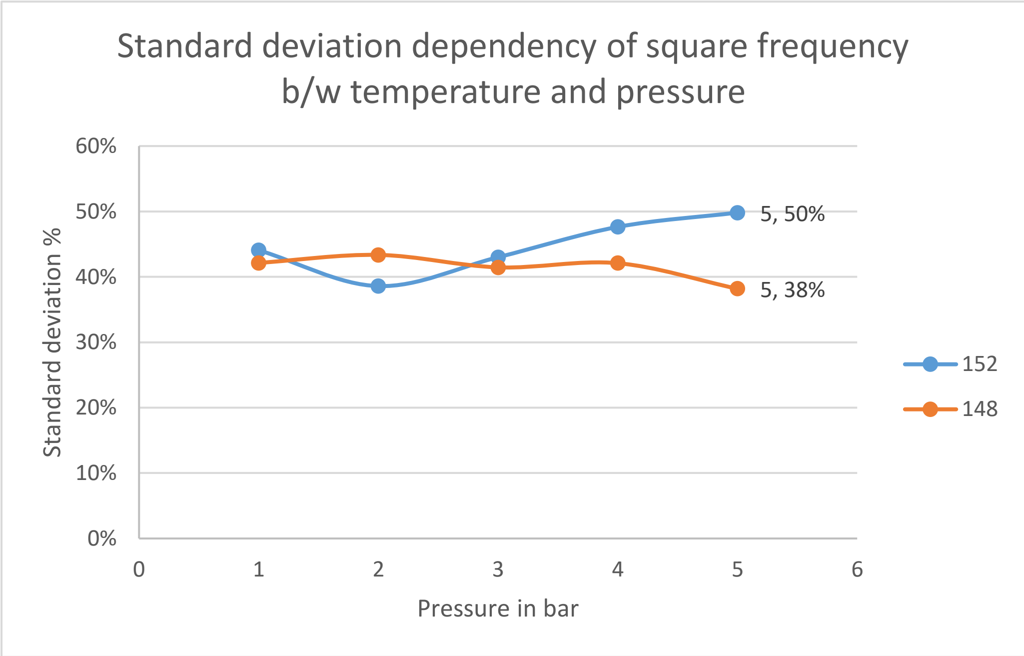

Figure 26. A chart showing the optical parameters dependency of pressure and Standard deviation, between the different temperature 152℃ and 148℃ by using square frequency generator

In the fig 26, show the squre wave from optical parameters of pressure and temperature, In that case the highest parameter from in 152℃, 0.5 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 50%. The lowest parameters form in 148℃, 0.5Mpa pressure, 10 s pressing time, the standard deviation value reached almost 38%.

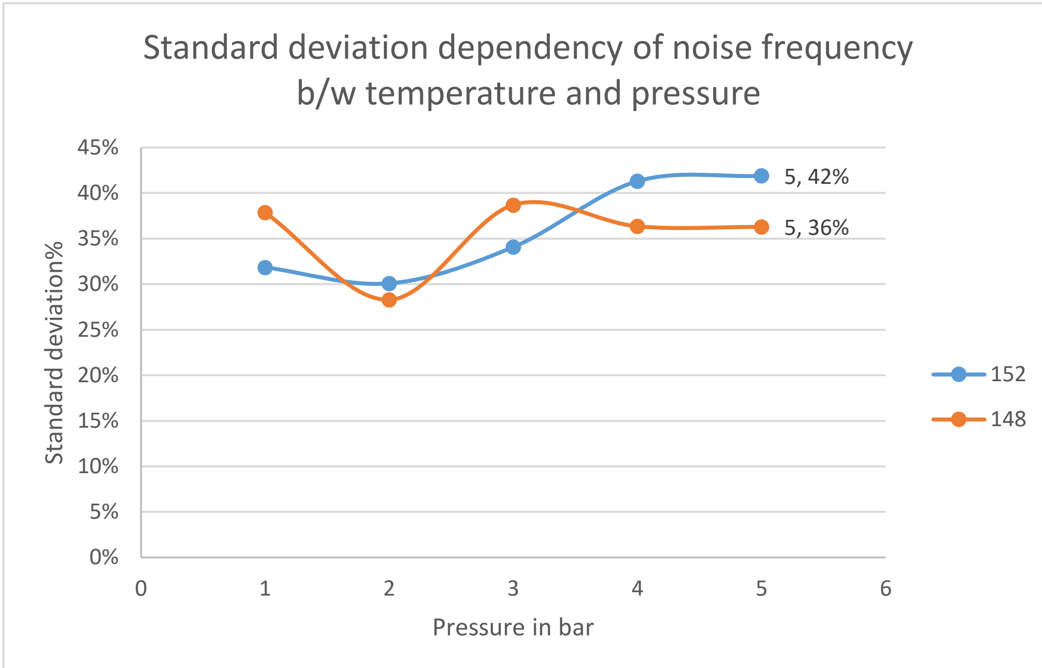

Figure 27. A chart showing the optical parameters dependency of pressure and Standard deviation, between the different temperature 152℃ and 148℃ by using noise frequency generator

In the fig 27, show the noise wave from optical parameters of pressure and temperature, In that case the highest parameter from in 152℃, 0.5 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 42%. The lowest parameters form in 148℃, 0.2 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 29%.

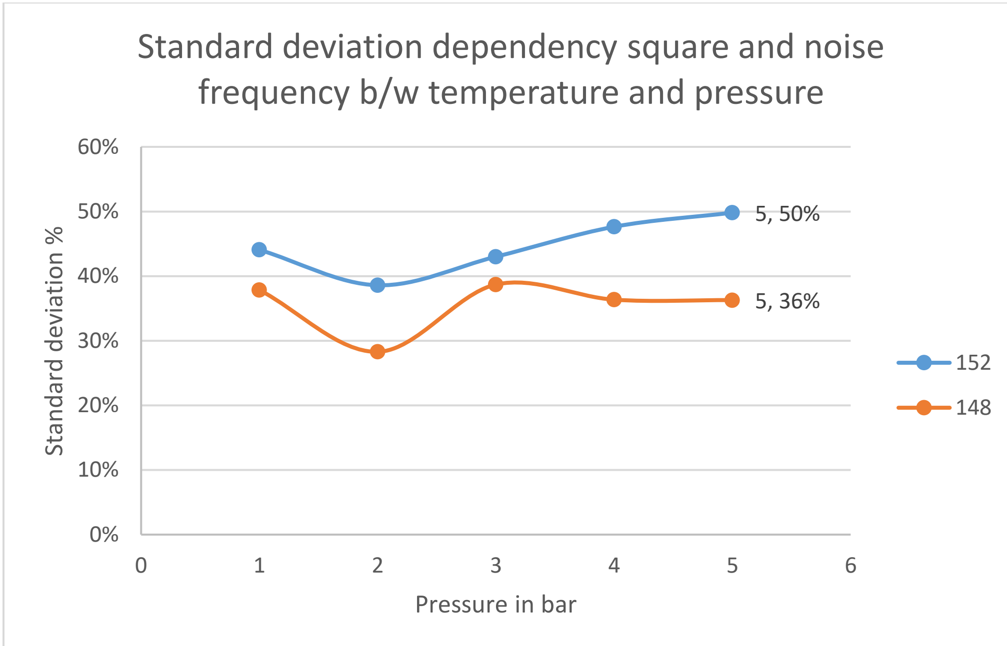

Figure 28. A chart showing the optical parameters dependency of pressure and Standard deviation, between the different temperature 152℃ and 148℃ by using both square and noise frequency generator

In the fig 28, show the square wave from optical parameters of pressure and temperature, In that case the highest parameter from in 152℃, 0.5 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 42%. The lowest parameters form in 148℃, 0.2 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 29%.

In the fig 28, the square wave from optical parameters of pressure and temperature, In that case the parameter from in 152℃, 0.1 Mpa, 0.2 Mpa, 0.3 Mpa, 0.4 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 45%, 39%, 42%, 49% , and then noise parameters form in 148℃, 0.1 Mpa, 0.3 Mpa, 0.4 Mpa, 0.5 Mpa, pressure, 10 s pressing time, the standard deviation value reached almost 39%, 39%, 37%, 37%.

In these results, Check the optical imprint technological parameters between the pressure and temperature, with the stranded deviation by using different pressure 1 bar, 2 bar, 3 bar, 4 bar, 5 bar, Time is 10 seconds, temperature 148℃ and 152℃ and then here using square, noise frequency generator and red laser (λ = 532 nm)

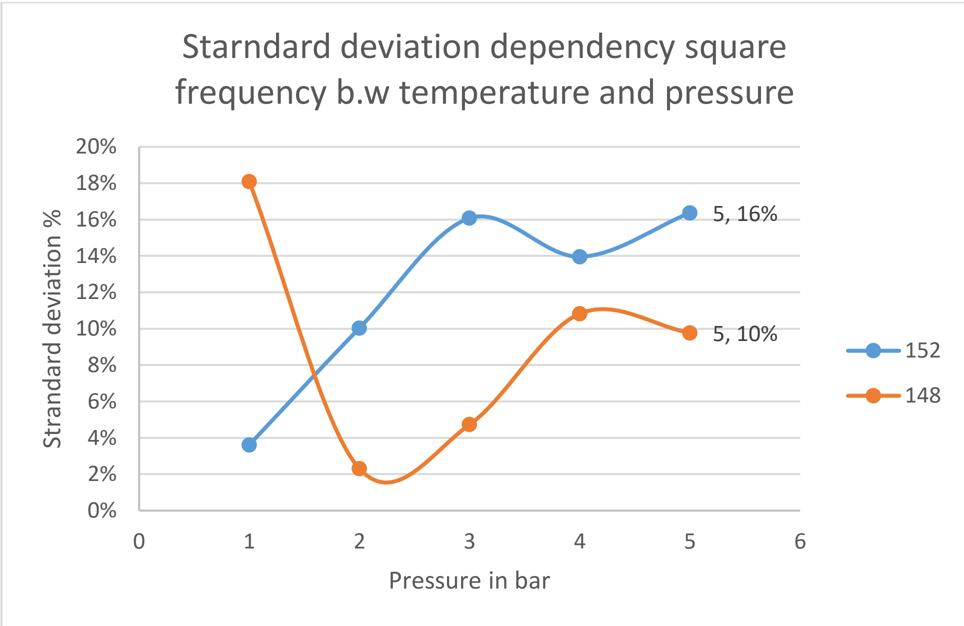

Figure 29. A chart showing the optical parameters dependency of pressure and Standard deviation, between the different temperature 152℃ and 148℃ by using square frequency generator

In the fig 29, show the square wave from optical parameters of pressure and temperature, In that case the highest parameter from in 152℃, 0.5 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 16%. The lowest parameters form in 148℃, 0.2Mpa pressure, 10 s pressing time, the standard deviation value reached almost 3%.

In the fig 30, show the noise wave from optical parameters of pressure and temperature, In that case the highest parameter from in 152℃, 0.4 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 25%. The lowest parameters form in 148℃, 0.3 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 8%.

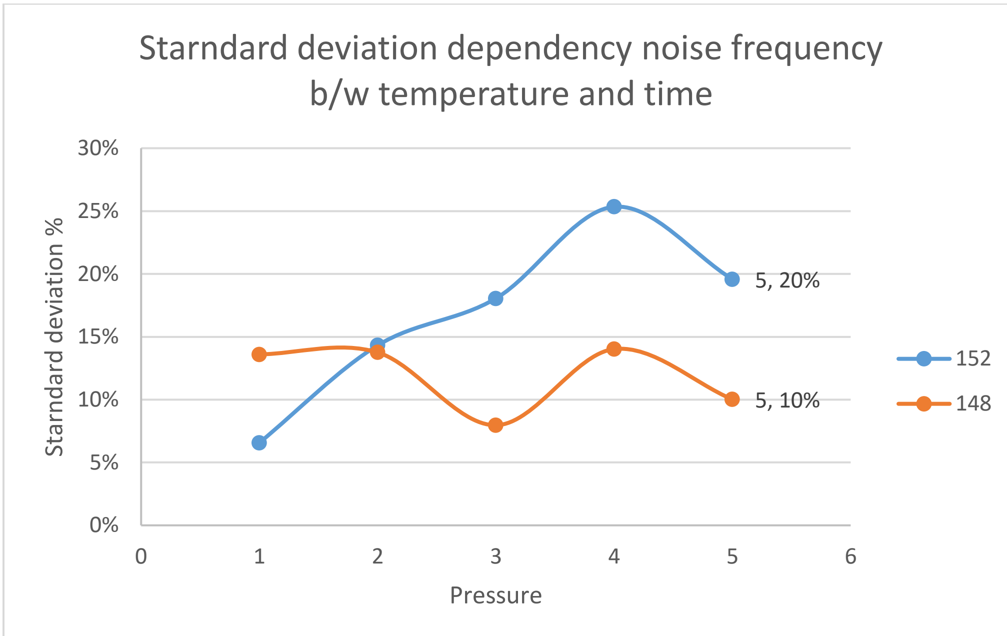

Figure 30. A chart showing the optical parameters dependency of pressure and Standard deviation, between the different temperature 152℃ and 148℃ by using noise frequency generator

In the figure.30, the square wave from optical parameters of pressure and temperature, In that case the parameter from in 152℃, 0.1 Mpa, 0.2 Mpa, 0.3 Mpa, 0.5 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 7%, 14%, 17%, 20% , and then noise parameters form in 148℃, 0.1 Mpa, 0.2 Mpa, 0.4 Mpa, 0.5 Mpa, pressure, 10 s pressing time, the standard deviation value reached almost 14%, 13%, 14%, 10%.

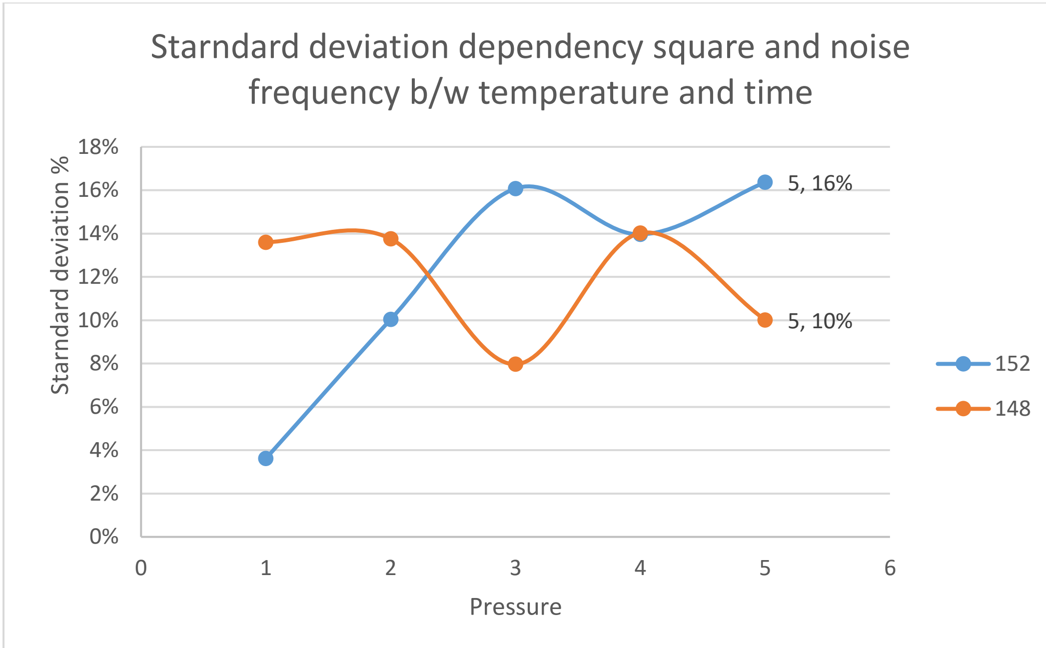

Figure 31. A chart showing the optical parameters dependency of pressure and Standard deviation, between the different temperature 152℃ and 148℃ by using both square and noise frequency generator

In the figure.31, the square wave from optical parameters of pressure and temperature, In that case the parameter from in 152℃, 0.1 Mpa, 0.2 Mpa, 0.3 Mpa, 0.4 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 3%, 11%, 16%, 14%, and then noise parameters form in 148℃, 0.1 Mpa, 0.3 Mpa, 0.5 Mpa, pressure, 10 s pressing time, the standard deviation value reached almost 13%, 8%, 10%.

In the fig 31, show the noise wave from optical parameters of pressure and temperature, In that case the highest parameter from in 152℃, 0.5 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 17%. The lowest parameters form in 148℃, 0.2 Mpa, 0.4 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 14%, 14%.

3.2 Influence of square and noise type excitation quality of replicated periodical microstructure:

In these results, Check the quality of excitation replicated periodic microstructure compared to the square and noise, with the diffraction efficiency by using different pressure 1 bar, 2 bar, 3 bar, 4 bar, 5 bar, Time is 10 seconds and then here using red laser (λ = 633 nm)

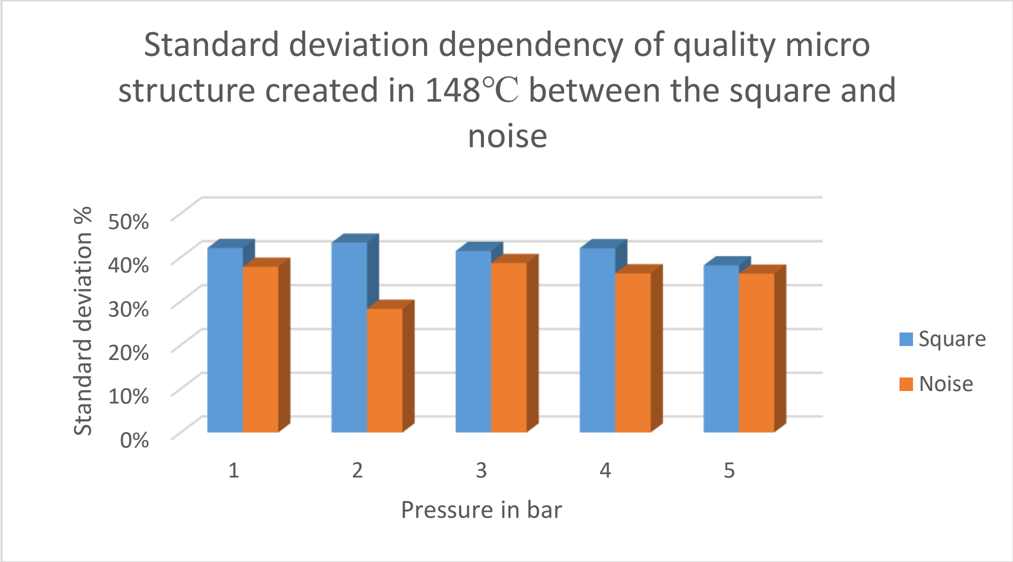

Figure 32. A chart showing the dependency of pressure and Standard deviation of excitation replicated periodical microstructures created in 148°C between the square and noise

In the fig32, show the square wave from quality of periodical microstructure compared to noise wave, In that case the highest quality of periodical microstructure was found in square wave, the specimen with process regimes of 148 temperature, 0.2 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 42%

In the figure.32,the square wave from quality of periodical microstructure, In that case the quality of periodical microstructure from in 148°C, 0.1 Mpa, 0.3 Mpa, 0.4 Mpa, 0.5 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 40%, 41%, 40%, 36% , and then noise wave form in 148°C, 0.1 Mpa, 0.2 Mpa, 0.3 Mpa, 0.4 Mpa, 0.5 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 37%, 27%, 38%, 32%, 32%.

In the fig33, show the square wave from quality of periodical microstructure compared to noise wave, In that case the highest quality of periodical microstructure was found in the specimen with process regimes of 152 temperature, 0.5 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 48%

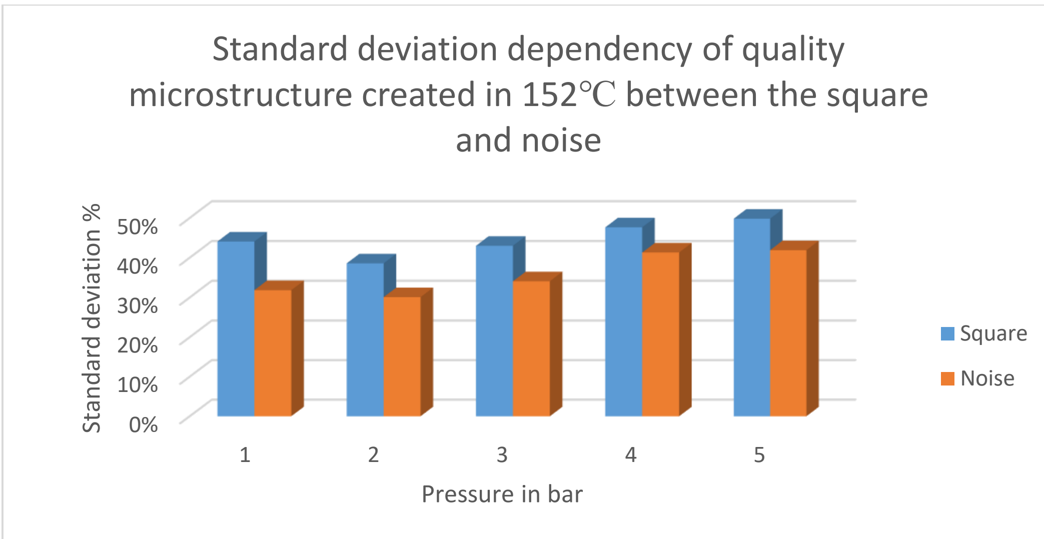

Figure 33. A chart showing the dependency of pressure and standard deviation of excitation replicated periodical microstructures created in 152℃ between the square and noise

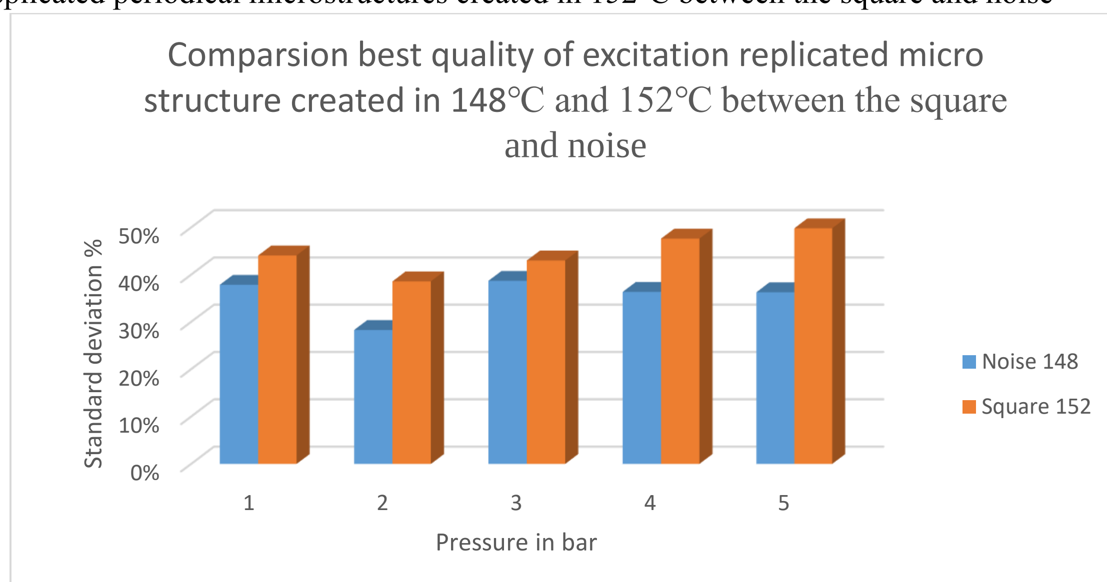

Figure 34. A chart showing the dependency of pressure and Standard deviation of excitation replicated periodical microstructures created in 148℃, 152℃ between the square and noise

Using Fig.34, it can be check that the microstructure replicated with the noise vibrating generator, pressing time is 10 s and 0.2 Mpa pressure has lower standard deviation value (27%) as well as low quality, the square vibrating generator, pressing time is 10 s and 0.5 Mpa pressure has highest standard deviation value (27%) as well as high quality.

In these results, Check the quality of excitation replicated periodic microstructure compared to the square and noise, with the diffraction efficiency by using different pressure 1 bar, 2 bar, 3 bar, 4 bar, 5 bar, Time is 10 seconds and then here using green laser (λ = 532 nm)

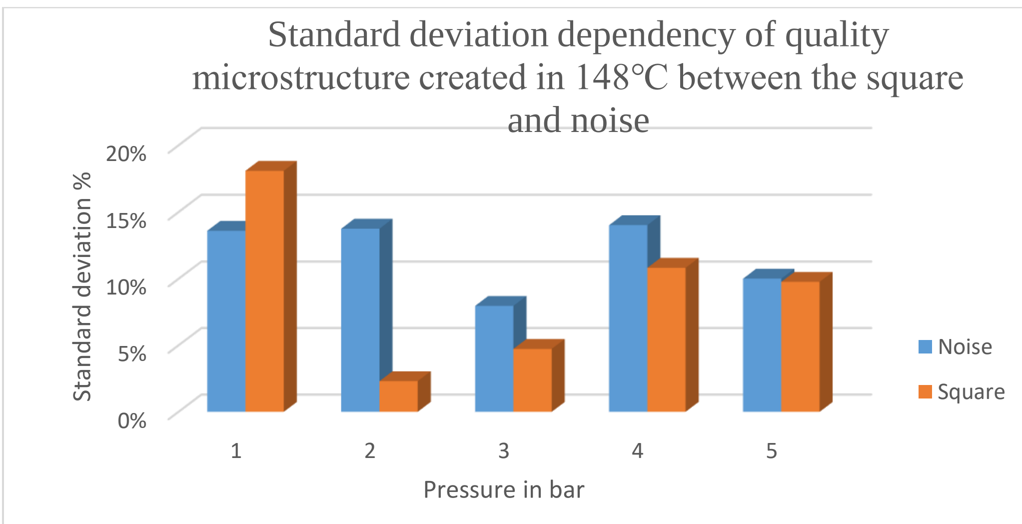

Figure 35. A chart showing the dependency of pressure and Standard deviation of excitation replicated periodical microstructures created in 148°C between the square and noise

In the fig 35, show the square wave from quality of periodical microstructure compared to noise wave, In that case the highest quality of periodical microstructure was found in the specimen with process regimes of 148 temperature, 0.1 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 17%.

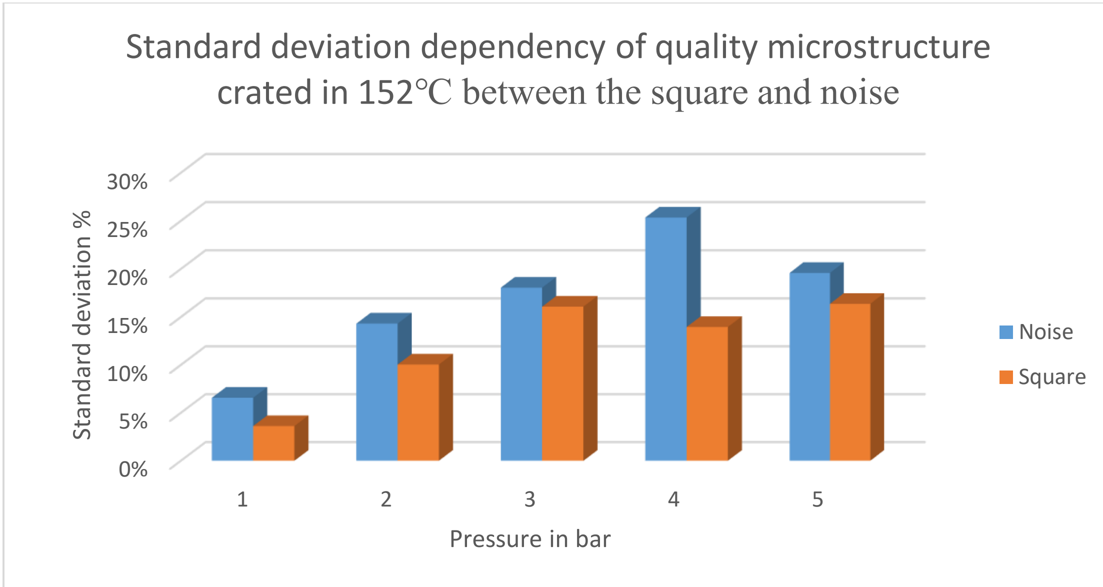

Figure 36. A chart showing the dependency of pressure and average diffraction efficiency of excitation replicated periodical microstructures created in 152 °C between the square and noise

In the fig 36, show the noise wave from quality of periodical microstructure compared to square wave, In that case the highest quality of periodical microstructure was found in the specimen with process regimes of 152℃ temperature, 0.4 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 24%.

In the figure.36,the square wave from quality of periodical microsture, In that case the quality of periodical microstructure from in 152℃, 0.1 Mpa, 0.2 Mpa, 0.3 Mpa, 0.4 Mpa, 0.5 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 3%, 9%, 15%, 13% , 15% and then noise wave form in 152℃, 0.1 Mpa, 0.2 Mpa, 0.3 Mpa, 0.5 Mpa pressure, 10 s pressing time, the standard deviation value reached almost 5%, 13%, 16%, 18%.

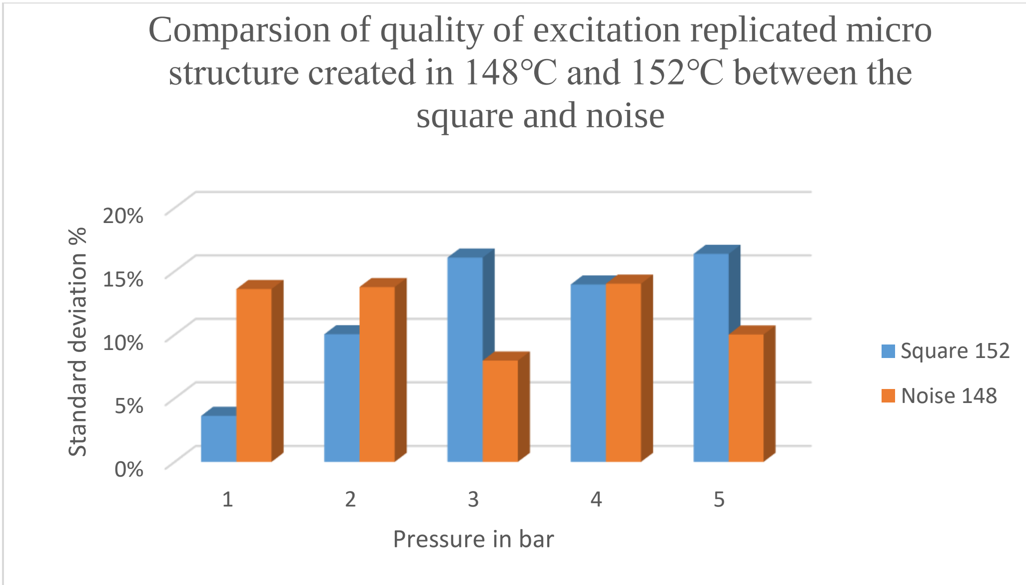

Figure 37. A chart showing the dependency of pressure and average diffraction efficiency of excitation replicated periodical microstructures created in148°C, 152 °C between the square and noise

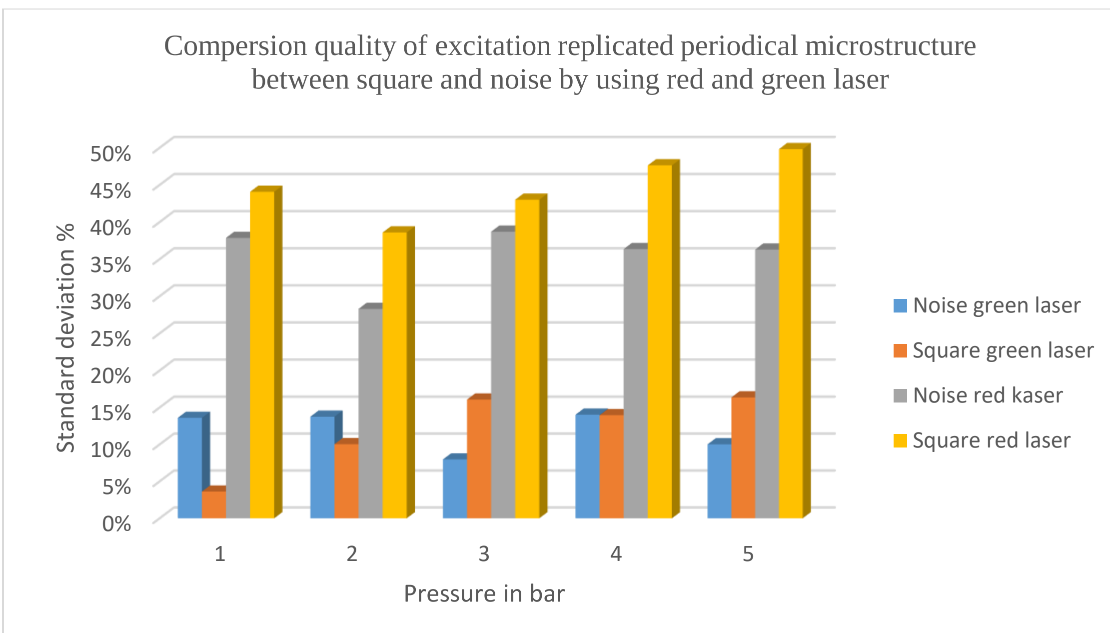

Figure 38. A chart showing the dependency of pressure and standard deviation of excitation replicated periodical microstructures created in148°C and 152 °C between the square and noise, both lasers red and green

Using Fig.38, it can be clearly seen that the microstructure replicated with the using red laser noise vibrating generator, pressing time is 10 s and 0.3 Mpa pressure has highest standard deviation value (39%) as well as high quality, as the same square vibrating generator, pressing time is 10 s and 0.5 Mpa pressure has highest standard deviation value (48%) as well as high quality.

Using Fig.38, it can be clearly seen that the microstructure replicated with the using green laser noise vibrating generator, pressing time is 10 s and 0.4 Mpa pressure has highest standard deviation value (13%) as well as high quality, as the same square vibrating generator, pressing time is 10 s and 0.1 Mpa pressure has highest standard deviation value (7%) as well as low quality.

4 Conclusion:

Experimental techniques of replicated periodical microstructure and discussion about the applications, laser technology, biochemical industry, astronomy, medicine, and optics are discussed in literature review. Square and noise excitations are generated using frequency amplifier. Mechanical hot imprint method, Diffractometer and vibroactive pad are used for analyzing the quality of replicated periodical microstructure.

Optical parameters of the study are defined by performing theoretical calculations. Calculations using two different temperatures 148℃, 152℃ and pressures of 0.1 Mpa,0.2 Mpa 0.3MPa, 0.4 Mpa, 0.5 Mpa are performed for determining the optical parameters. square excitation at 152℃ at all defined pressures is observed to be the most suitable compared to noise excitation from the dependencies created. From the results obtained, the optical parameter at 152℃ gives the best results of 50%.

Square and noise excitations are compared at a frequency of 8.460 KHz and an amplitude of 5V to determine the quality of thermally replicated periodical microstructure. According to the results, the quality of periodical microstructure observed in case of square excitation with wavelength 633 nm is 48% at 0.5 MPa. It is better compared with noise excitation. In case of changing the wavelength to 532 nm, the replicated periodical microstructure quality obtained with square excitation is 15 % at 0.3 MPa. It proves that the square excitation provides better results than the noise excitation.

5 References:

1. Palmer Ch. *Grating Handbook* // Newport Corporation / 2014. pp. 204;
2. Loewen E. *Diffraction grating handbook 4th edition* // Richardson Grating Laboratory / 2000, pp. 143;
3. Gale M. T. *Replication Technology for Holograms and Diffractive Optical Elements* // Journal of Imaging Science and Technology/vol. 41, 1997, pp. 211-220;
4. Janušas G. *Formation and investigation of periodical microstructures using coherent radiation* // Doctoral dissertation: Technologic sciences, mechanical engineering / Kaunas, 2008, pp. 102;
5. Worgull M., Hetu J. F., Kabanemi K. K., Heckele M. *Modeling and optimization of the hot embossing process for micro- and nanocomponent fabrication* // Microsystem Technologies/vol. 12, September, 2006, pp. 947-952;
6. Nadir A. *Roll to roll UV embossing technology* // The Holography Times / November, 2010. pp. 12-14;
7. Piotter V., Hanemann T., Ruprecht R., Haußelt J. *Injection molding and related techniques for fabrication of microstructures* // Microsystems technologies/vol. 3, May, 1997, pp. 129-133;
8. Su Y., Shah J., Liwei L. *Implementation and analysis of polymer microstructure replication by microinjection molding* // Journal of Micromechanics and Microengineering/vol. 14, 2004, pp. 415-422;
9. R. Šakalys, G. Janušas, A. Palevičius, R. Bendikienė, R. Palevičius. *Microstructure replication using high-frequency vibroactive pad* // Journal of microstructure replication/vol. 21, 2015, pp. 134-140;
10. Giedrius Janusas, Elingas Cekas, Rokas Sakalys, Ieva Paleviciute, Evaldas Semaska. Experimental and modeling means for analysis and replication periodical microstructures / vol.20,2013,pp.135;
11. Loewen E. G., Popov E. *Diffraction Gratings and Applications, Optical Engineering Series* // Marcel Dekker, New York – Basel / 1997, pp. 601;
12. Xie H., Shang H., Dai F., Li B., Xing Y. *Phase shifting SEM moiré method* // Optics & Laser Technology / vol. 36, June, 2004, pp. 291-297;
13. Sai H., Yugami H., Akiyama Y., Kanamori Y., Hane K. *Spectral control of thermal emission by periodic microstructured surfaces in near-infrared region* // Optics InfoBase / vol. 18, July, 2001, pp. 1471-1476;

14. Medway Optics LTD [interactive] [retrieved on 27th of October], from <http://www.medwayoptics.com/product4.htm>;

15. Diffraction gratings: technical information & general applications http://www.tau.ac.il/~phchlab/experiments/hydrogen/diffraction_gratings.htm [Viewed on 2009.03.20];

16 X. M. Zhang, Q. W. Zhao, T. Zhong, A. B. Yu, E. H. Khoo, C. Lu and A. Q. Liu. variable nano-grating for tunable filters. Hong Kong: Hong Kong Polytechnic University 2005,pp.1-9;

17 Diffraction Grating General information http://www.meshtel.com/grating.htm [Viewed on 2016.12.20];

18 Diffraction Grating General information http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/grating.html

[Viewed on 2016.12.20];

19 Reflective Ruled Diffraction Gratings http://www.edmundoptics.com/onlinecatalog/displayproduct.cfm?productid=1896 [viewed on 2016.12.15];

20 Narijauskaitė B., Palevičius A., Gaidys R., Janušas G. *Polycarbonate as elastoplastic material model for simulation of hot imprint process of microstructure* // 25th International Symposium on Polymer Analysis and Characterization / June, 2012, pp. 23;

21 R. Šakalys, G. Janušas, A. Palevičius, R. Bendikienė, R. Palevičius. *Microstructure replication using high-frequency vibroactive pad* // Journal of microstructure replication/vol. 21, 2015, pp. 134-140;

22 He Y., Fu J., Chen Z. *Research on optimization of the hot embossing process* // Journal of Micromechanics and Microengineering/vol. 17, 2007; pp.2-15;

23 Popov E. *Gratings: Theory and Numeric Applications* // Institut Fresnel / 2012, pp. 23;

24 Binnig, G., C.F. Quate, and C. Gerber, Atomic Force Microscope. Physical Review Letters, 1986. 56(9): p. 930.