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RESEARCH ARTICLE

An Alternative Approach to Production of Small Scale PV Module Laminated by Pressure Method

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ABSTRACT

This study involves production of the PV modules that may be used to small scale applications. It is aimed to design a procedure whereby production of PV modules could be realized under ordinary conditions by persons having no prior technical skill. With this goal, a simple to use, lamination system is designed and produced using the Solidworks software program. The electrical and mechanical parts are organized in such a manner that the lamination process could be effected either by using vacuum or high pressure. Both methods are used in preparing PV modules. Visual inspection and performance of modules prepared by either method showed no significant difference. However, the high pressure method provides an advantage since under ordinary conditions, it is easier to obtain high pressure, even mechanically. The designed lamination system is also light weight and portable. Also it can be envisioned that the system can be designed lighter by decreasing the sizes of the supporting materials to be used in application of the pressure.

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Introduction

The main disadvantage of using solar energy systems is the unstable level of solar energy which frequently changes day by day or seasonally. To eliminate this disadvantage and to increase the usage of solar energy, it is necessary to store energy in batteries. The stored energy may also be used at night time when there is no solar insolation. The small scale applications such as the lighting and signaling systems operate with this aim (Aktacir et al., 2008). In order to increase the output and life-span of PV modules and to protect against the corrosion or mechanical constraints caused by outdoor conditions, lamination system is used (Saly et al., 2002).

During laminating, a Standard PV module is located into lamination system (laminator) which has a vacuum pump to get rid of air bubbles inside the encapsulation material which melts at 150 °C. Also a mechanical pressure is applied by laminator to remove the air bubbles and to fix the string location (Dross et al., 2006a).

In production of industrial solar modules, mounting materials and labor costs amount to 30% of PV solar panel cost. Also, more than half of the energy spent during production is actually spent during lamination process. Because the process is quite complicated, expensive industrial laminating systems are employed (Dross et al., 2006a; Lange et al., 2011). This

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makes it difficult to build these systems in ordinary conditions and environment.

In this study, a small PV module laminating system has been designed to serve mainly the requirements for small scale applications. It has also been aimed that the laminator can be used, in many different environments, by an operator who is not necessarily a technician but only has a little training. Especially, in countryside where there is no road lighting, the residents can contribute to the production of module to provide lighting of roads, signs and signalization. It has been also clarified the necessity to make the usage of the system easier in order to benefit from semi-professional labor. While the laminator carries out the laminating process of PV cells, only mechanical pressure has been preferred instead of vacuum and mechanical pressure applied at the same time. In the experiments, production by only mechanical pressure has been compared with vacuum application, and as a result no difference has been detected. Thus, both lamination process has been simplified and the need for vacuum pump used in industrial applications has ceased.

Lamination Systems

A standard PV module string is glass-EVA-cell-EVA-glass or glass-EVA-cell-EVA-Tedlar® (Krauter et al., 2011). Standard encapsulation method (EVA lamination between front tempered glass and rear layer) is used in industrial solar cells (Dross et al., 2006b). Also, Tedlar® is used at the rear layer in order to increase the resistance against humidity and outdoor conditions (El Amrani et al., 2007). The string is located into the laminator so as to remove the air bubbles in encapsulation material which is in solution at around 150 °C. While the air bubbles are removed from laminators and the string position of solar cells is saved through removing the air inside by vacuum, a mechanical pressure is also carried out (Dross et al., 2006b).

Industrial lamination systems

Industrial lamination process which is one of the most expensive and complicated stages of PV module production process in industrial field is described below (Nowlan et al., 2000; Nowlan et al., 2002):

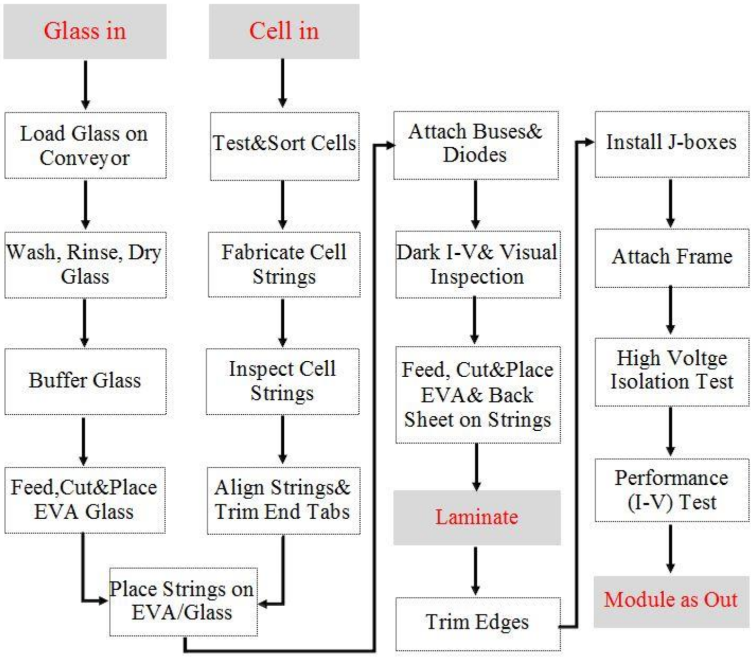

Figure 1. Process flow module assembly for crystalline silicon solar cells (Wiese et al., 2011).

As seen on Figure 1, Solar module is consisted of the Glass used in lamination progress, Solar cell, EVA and Tedlar® after a meticulous progress (Wiese et al., 2011).

The glass is cleaned, rinsed and placed into buffer tank before placed on the conveyor. The Solar cells are connected in series after testing and classifying. The Solar cell series are placed on the Glass, which is already collected with EVA after last tests and controls. Last inspections and tests of the Solar module drafts can be done after matched the connection terminals and protection diodes. One more EVA part is placed on to back contact of the Solar module draft and the heating and lamination progress is started (Nowlan et al., 2002; Grunow & Krauter, 2006). After completing the lamination progress there is needed to cut and trimmed the extensions and outburst EVA parts. This process is done on the conveyor called Cut & Trim. Output pins of produced Solar module are connected with plus and minus terminals and covered by frame to protect the edges and sides of Solar module against external effects (El Amrani et al., 2007; Krauter et al., 2011). After high voltage isolation tests and the tests related open circuit voltage, short circuit current values the Solar module is ready to install a Solar system (Wiese et al., 2011).

There is investigated and discussed some solutions aimed to shorten the duration of the lamination (Hogan et al., 1993), to decrease defective production rate (Krauter et al., 2011), to design more automated systems (Nowlan et al., 2002), to speed up and to decrease the expenses of the test progress (Meekhun et al., 2008).

Most of these studies increase the quality and efficiency, but they cause to make the system more complicated, confusing and more expensive. EVA (Ethylene Vinyl Acetate) was presented at the end of the years 1970's and with the vacuum lamination system can be guaranteed the modules about 20-25 years. This feature can be ensured because of the chemical feature of EVA (Ethylene Vinyl Acetate). Komp et al. (2011) thought that if there is tried to change chemical feature of EVA or used other versions of it, that can be needed less vacuum. In our study we tried and succeed a new design, that is not needed any vacuum with it.

Materials and Methods

The Designed Lamination System

Solidworks Design: In lamination system, as we take the considerable size of PV modules into consideration, Solidworks design (Figure 2) has been formed in order to provide the function of portability.

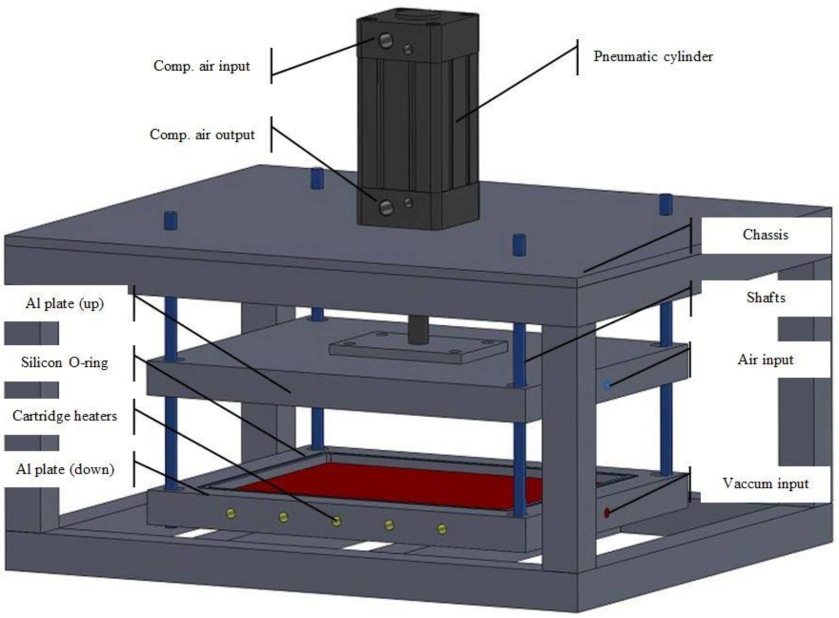

Figure 2. Solidworks design.

The Form of the System: The system components manufacturing and assembly process carried out, after the solid model of the system has been formed. To laminate the PV cells, a control unit has been formed in order to check out parameters to be applied, pneumatic system's up/down movement and heat control and to turn on/off the system on laminator. The figure about the laminating system (laminator) is below (Figure 3).

Figure 3. Lamination systems.

While in mechanical pressure method a compressor is used, in vacuum method a vacuum pump and a control unit is used. Although both have been placed in the experiment, there is no need for the vacuum pump in the designed system.

Control Unit: It has been formed in order to control the process of thermic operation of lamination. Usage of PID controller has been preferred to optimize the parameters identified. The electrical circuit about the system mentioned is shown in Figure 4.

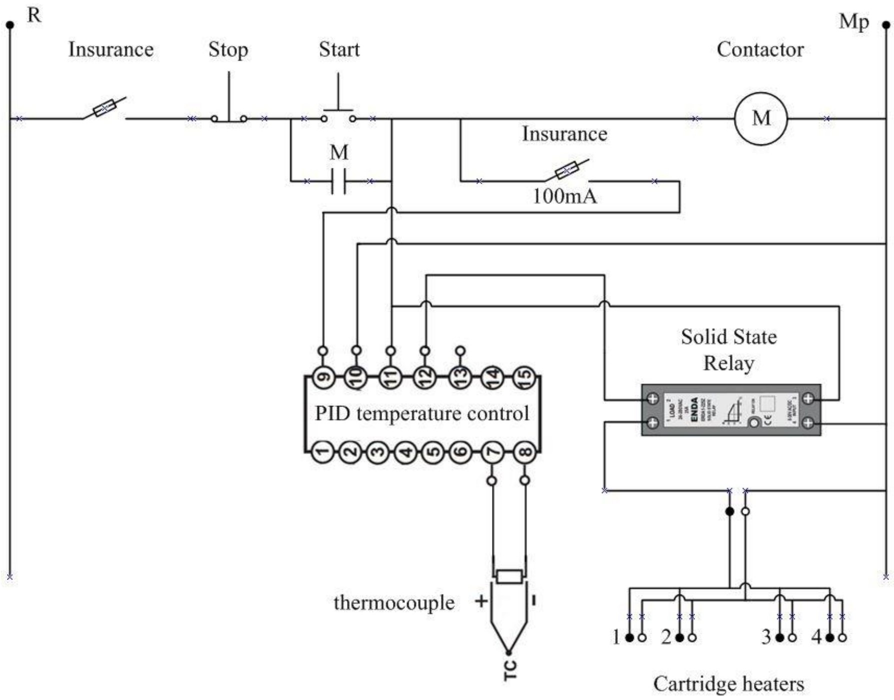

Figure 4. The electrical circuit diagram about the control unit.

In choosing cartridge resistors used in lamination system, the calculation has been evaluated according to the heat desired by using the weight of aluminum sheet and specific heat. It has been calculated that cartridge resistors would give the heat of 250 °C. The following calculation, herein the m is the weight equals to 14 kg, the C_p is the specific heat (0.24 cal/g °C for Al), the ΔT is the difference between the initial temperature and the desired temperature (25-250 °C), the t is the time determined as 30min, has been used for the power.

$$P = \frac{m \times C_p \times \Delta T}{0{,}8604 \times t} \quad (1)$$

According to the results of the calculations, the power which is necessary for aluminum sheet going up from 25 °C to 250 °C is about 1757.32 W. Four cartridge resistors of 500W have been used to provide this power.

Design and Production of Small Scale Solar Module

Design of small scale PV module

In this study, 12 different tests with solar cells at different criteria and technical properties and which are in the same current and voltage have been applied and small scale PV module designs have been applied. In the experiments regarding this article, the reason why solar cell order in Figure 5 has been chosen is due to the fact the period shortens because of the electric connection.

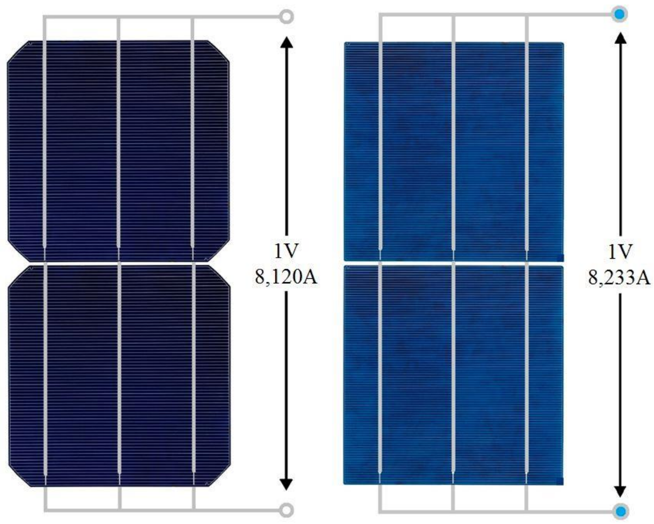

Figure 5. Sequence of PV cells.

Electric connections applied solar cells are formed with the same property and size lamination materials seen in Figure 6.

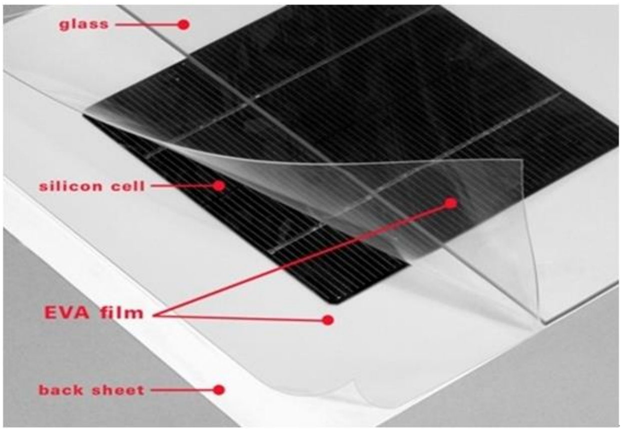

Figure 6. PV module structure (EVA, 2022).

In manufacturing applications, special glasses with high transmittance and endurance are used in the front surface of the PV module. These glasses are called tempered glass. In the applications and experiments instead of this glass 2 mm standard window glasses, sizes of which are changing according to the cell order has been used. In order to increase the clutch and holding endurance between the layers Etil Vinil Asetat (EVA) is used in the lamination process (Komp et al., 2011). Technical properties about used EVA material are given in Table 1. Technical properties about used Tedlar® are given in Table 2.

Table 1. Technical properties about EVA material (EVA, 2022).

Properties	
Thickness	≈ 0.45
Density	0.957 g/cm^3
Breakdown elongation	900 ~ 1000 %
Elasticity modules	4,8 MPa
Electrical resistivity	10^{14} Ω cm
Melt index (190 °C/2.16 kg)	43 g/10 min
Melting point	63 °C
Water absorption	0.05% ~ 0.13%
Refractive index	1.482

Table 2. Technical properties about Tedlar® material (DuPont™, 2014).

Property	**Typical Value**	**Test Method**	**Test Condition**
Physical			
Density	1.37-1.72 g/cc	ASTM D-1505	22 °C (72 °F)
Impact Strength	10-20 in lb/mil	ASTM D-3420	22 °C (72 °F)
Water Vapor Transmission	9-57 g/m2d	ASTM E-96	39.5 °C, 80% RH
Refractive Index	1.46 nD	ASTM D-542	30 °C (86 °F)
Tensile Modulus	300-380x103psi	ASTM D-882	22 °C (72 °F)
Thermal			
Continuous Use	-72 to 107 °C		
Short Cycle	175 °C		
Chemical Resistance			
Weatherability	Excellent	Florida exposure	Facing South at 45° to horizontal

Production of small scale PV module

In this study in order to make a comparison with the further experiments in experiment-1 vacuum lamination has been applied. In the further experiments without using vacuum pomp under thermal processing only mechanical pressure has been applied.

Results and Discussion

In experiment-1, a 330x170x4 mm module has been produced by using mono-crystal PV solar cells. Temperature, vacuum and time flow graphics regarding the production mentioned are given in Figure 7.

When the module which is the result of experiment-1 is studied carefully it is clearly observed that air bubbles those can cause refraction and reflections of sun rays are not formed. Also there hadn't been any refraction or aberration in solar cells.

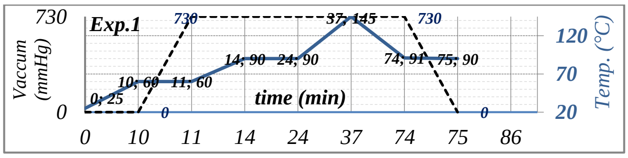

Figure 7. Temperature, vacuum and time flow graph about experiment-1.

In experiment-2, a 325x190x4 mm PV module has been produced by using 15.6 cm x 7.8 cm sized poly-crystal solar cells. In experiment-2 required PV module couldn't be produced due to the fact that enough pressure couldn't be applied by silicon plate and silicon plate (balloon) has lifted the upper aluminum plate.

In experiment-3, a 32.5 x 17 cm sized PV module has been produced by using 15.6 x 15.6 sized mono-crystal solar cells. Protection glass in the front has been broken during the removal procedure from the reservoir after the lamination process but no refraction has been observed. The lifting problem of aluminum plate observed in experiment-2 has also been solved by mechanical locking in this experiment.

In experiment-4, as well as in other experiments, metal sheet has been used to distribute of pressure on the upper surface of the structure. At the end of the lamination process, structure has been difficult to remove from the reservoir as in previous experiments. Also it has been observed that the solar cell orders have shifted with two-stage pressure (60 °C / 0.5 Bar - 90 °C / 1 Bar).

In experiment-5, in order to remove the sandwich construction and the protection glass properly without any problem and without breaking the glass, combining the construction and the back edge border of metal sheet has been tested. Even though this has resulted positive removal of the sandwich construction has been a difficult process. In experiment-5, in order not to shift the solar cell orders, single-stage pressure has been applied in 60 °C. With this process it has been observed that the solar cell orders have not shifted. Also it has been observed that formation of air bubbles has been at negligible level after the lamination process.

In experiment-7, the problem of the removal of the sandwich construction in the earlier experiments have been copied by placing two different metal sheets in two different sizes both in the upper and lower layers of it. But a shift in solar cell orders has been observed.

In experiment-8, in order to cope with the problems during the removal of the construction an aluminum foil has been used and the process has been completed without any problem. Formation of the air bubbles has been at a negligible amount and there hadn't been any shift of the solar cell orders. Breaking of the protection glass during the production period has shown that the heat has not been distributed properly. Increasing the lamination process to 143 ºC shows that the sandwich construction clutched better.

Despite breakings, aluminum foil has been used until experiment-10. But in experiment-10, copper sheet has been used in order to distribute the temperature properly. The deformation of copper sheet during the temperature change disabled it to grasp the surface of the glass properly and caused irregular distribution of the temperature. As a result, the breaking problem hasn't been solved.

In experiment-11, aluminum foil and copper sheet hasn't been used and the problem has been solved by removal of the structure after cleaning the melt EVA totally from the outer parts. After the production the formation of air bubbles has been observed at a negligible amount. Also there hasn't been any refraction in the glass or shift in solar cell orders. As the lamination temperature has been in 145 ºC, it has proved that the temperature has been ideal for the layers clutch level.

In experiment-12 by renewing the removal process of the sandwich structure the process has been confirmed. By adjusting the pressure rate to 1 bar, at the end of the production process formation of air bubbles has been observed to be less than in experiment-11 and at a negligible amount. Also there hasn't been any refraction in the glass or shift in solar cell orders. Clutching level of the module produced is at desired level. Temperature, pressure and time flow graphics regarding the production mentioned are given in Figure 8.

Pictures of the productions as a results of these experiments are as in Figure 9.

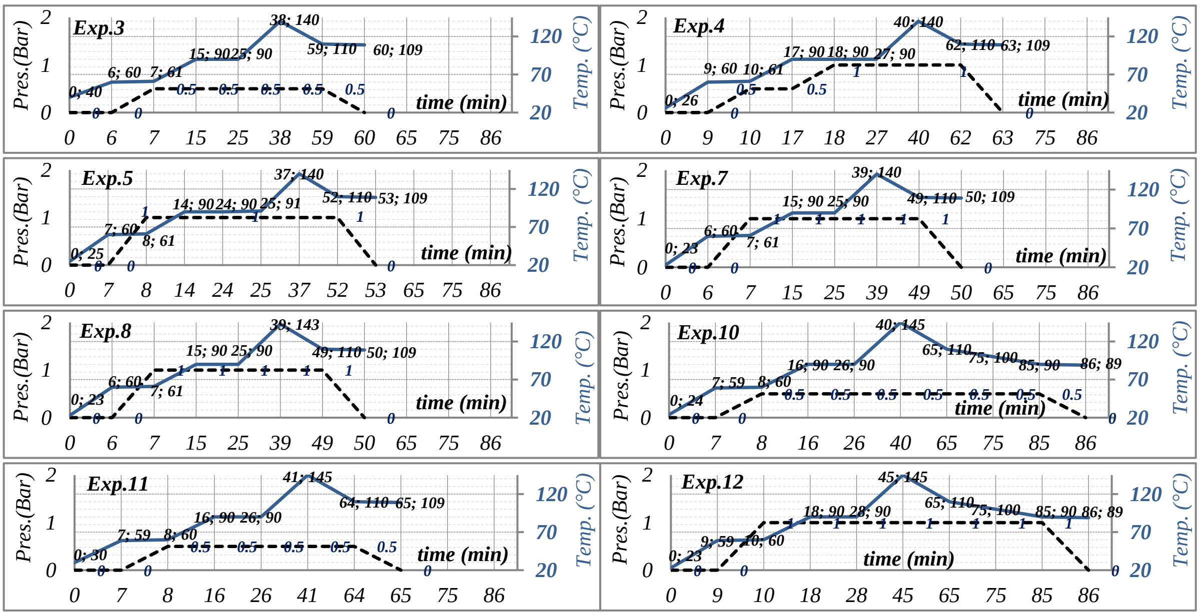

Figure 8. Temperature, pressure and time flow graphs about experiments carried out by pressure method.

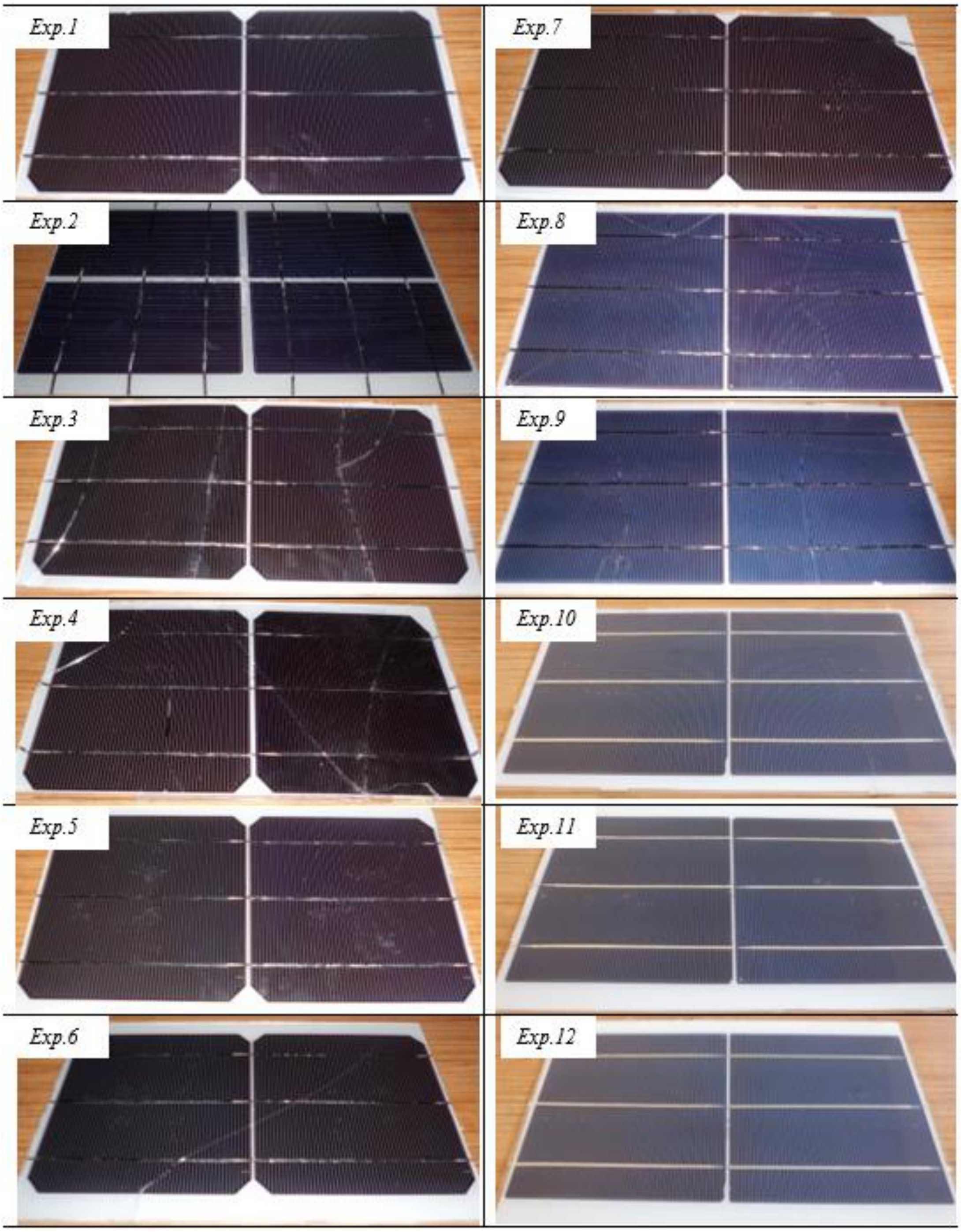

Figure 9. View about productions obtained by the method of vacuum and pressure.

Conclusion

Generally, as both vacuum and pressure methods are used together along with the production period of small scale solar modules, it necessitates the system to use both the vacuum pomp and the unit to make pressure along with itself. In order to extend the lamination system and make it portable peripherals has to be reduced. That's why in our study our lamination system has been designed for only temperature usage and more portable and useful device has been produced. In order to compose required pressure and apply the ideal parametric pressure rate low power compressor has been used. Also in order to compare the results those have been achieved by using the vacuum method in test platform with the parametric values of the pressure method, units those will help the application of the vacuum method have been added to the system temporarily.

In experiment-1, first, vacuum method has been used in production for comparison. Achieved parametric values have been compared with the results of the further 11 experiments in which mechanical pressure have been used. By the help of these comparisons, at each experiment period by making changes in parameters like pressure, temperature and time, an equivalent production result as in experiment-1 has been achieved at experiment-12 by using only mechanical pressure.

As a result of the experiments with the lamination system developed by using only mechanical pressure even though the staff who is going to use the device will have limited knowledge and experience he/she shall be able use it in various places and conditions. In the light of the results achieved, it has been obviously seen that in existing sizes, lighter and more portable lamination systems can be designed if more heat tolerant and lighter composite materials are chosen. Also it can be envisioned that the system can be designed lighter by decreasing the sizes of the supporting materials to be used in application of the pressure.

Conflict of Interest

The authors declare that they have no conflict of interest.

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