Comparison of Expansion Properties of Hot Water Valve from Three Different Materials

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Abstract
Polyamide stoiren acrylonitrile (SAN), polyamide 6.6 (PA66) and polymethyl methacrylate (PMMA) are three different materials considered as a possible alternative instead of hot water valve, produces by the company through conventional method by plastic injection machine. The goal of this paper is to propose the most suitable alternative among the three ones, using the examination of the thermal expansion coefficient and study the characteristic implication of different air pressure and temperatures simultaneously. The study was conducted with the specific designed experimental assembly and strain gauge software. The experimental results advise PA66 material as most suitable alternative of brass hot water valve.

1. Introduction

Increasing competition in the industry every day forces manufacturers finding new solutions for optimal costs' levels. Today, composite materials that are easy to manufacture, fast and cheap, but can withstand all working setbacks, have become preferred instead of production materials with high raw material costs. PA66, SAN and PMMA materials were selected, which are materials that can be produced more economically and quickly and can withstand the operating temperatures of the hot water valve, when considering the operating temperature of the hot water valve produced from the patented brass ($CuZn40Pb_2$) material of the company. Values obtained using strain gauge are compared using graphs.

The valve, which is made of brass material in the study, is produced by the company by casting method. In order to become the final product after production, processes are also required. Both the periods in the production method and the need for additional operations after production create October costs on the product. Given all these costs, it has made it mandatory to use a material that is cheaper, easier and has faster production in place of brass material.

In all areas, research on polymer-based composites has also increased with the increase in the need for lightweight but high-performance materials thanks to industries that are developing with high acceleration, such as the automotive, aerospace and defence industries [1]. The biggest reason for choosing composite materials is that they have low weight, high strength, chemical and corrosion resistance, high thermal performance properties [2].

Composite materials expected of a property of two or more elements created by bringing new and superior for the purpose [3]. Formed by making changes in the ratios of the components of the composite material can become superior. Composites are divided into fiber-reinforced, grain-reinforced and stratified composites. Stratified composites are formed by combining two or more layers [4]. In an elastic body subjected to thermal effect, various stress areas are formed according to the state of the boundary conditions and the temperature change function. Elasticity equations related to this topic have been deduced [5].

Expansion along with the increase in temperature, expansion occurs in all dimensions in solids. An expansion that occurs at length, widht and height is called a linear expansion. As a result, it is seen as the elongation of different materials at the same temperatures decidedly. Therefore, the amount of expansion formed in solids depends on the expansion coefficient of the materials. The amount of expansion is equals to $\Delta L = L_0 \cdot \lambda$. Here, the amount of expansion in the size of the solid is called $\pm L$, the

initial dimension of the solid is called L_0, the temperature change is called ± T, and the coefficient λ is called the coefficient of thermal expansion or the coefficient of expansion in size. The expansion coefficient is a characteristic property for substances. Just as solids expand, plasters and gases expand. Expansion in solids and liquids is a distinctive feature, while expansion in gases is not a distinctive feature. Since the expansion of materials is also in the micrometer order, the methods to measure the expansion must be very precise. For this reason, strain gauge method, capacity method, interference methods were used in the measurement of the expansion coefficient [6].

For accurate detection of the expansion amounts in the strain gauge valves that were designed for use in this study, they were glued to make a with 45° angle so that they could measure both coordinate systems. Calibration operations were performed and the instantaneous pressure and temperature obtained from the valves were recorded automatically. In the assembly designed for the simultaneous application of all conditions of three different valves designed for the experiment, apparatus were used to apply the given pressure to the valves at the same time.

2. Materials and Method

In the experiments, a special design experimental assembly was made so that the valves produced for comparison could be applied to air with different temperature and pressure values under the same conditions. In the experiment, three different materials were used as an alternative to the valve produced from brass $CuZn40Pb_2$. These materials used in the study are stoiren acrylonitrile (SAN), polyamide 6.6 (PA66) and polymethyl methacrylate (PMMA). The reason these materials are chosen is because they are easy and affordable as raw materials in the industry. The patent of the valve belongs to the company and its production is currently ongoing [7].

Figure 1 shows the hot water valve in three perspectives, produced from three different materials and used in the experiment, in which the company has a patent [7].
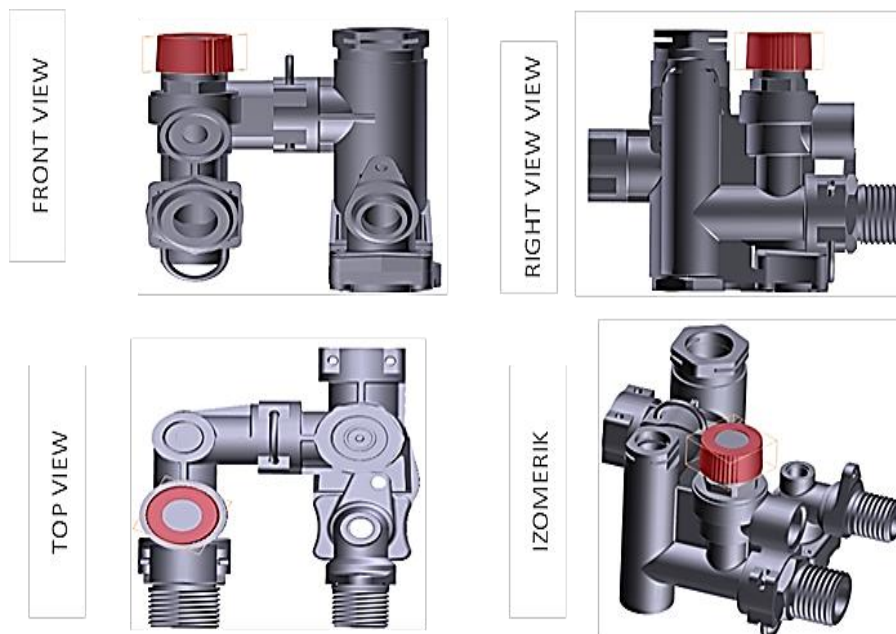

Fig. 1. Views of the valve from different angles

The mechanical properties of the brass $CuZn40Pb_2$ valve, Fig. 2 (a), produced by the company by casting method are much higher than that required for the hot water valve used in the combi boiler.

In order to meet the combi boiler cost safe plan, the company need to determine the material with lower mechanical properties, less cost, shorter production time, and doesn't need additional after production processing, but meets the expected mechanical properties where necessary. All these requirements enforces three polymer materials easily available in the market and at much more affordable prices to be determined as suitable.
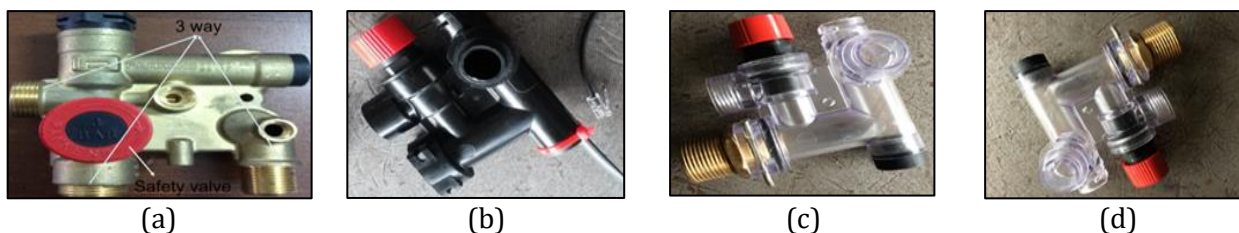
Fig. 2. Materials used: (a) brass CuZn40Pb$_2$; (b) PP66; (c) SAN; (d) PMMA

Polyamide 6.6, first found by Schlack in 1938, became widespread with its use in World War II. Polyamide 6.6 have high tensile strength, high resistance to abrasion and chemical [8]. Discoloration and reduction occur when exposed to heat for a long time. It ignites easily. Extensive research has been conducted to determine the advantages of polyamide 6.6 [9]. This material has the property of heat resistant, and hardness. In addition to its superior properties, it is widely used in the automotive industry as it can withstand solvent and hot water.

Styrene-acrylonitrile copolymers, found in 1937, are hard and brittle materials that are resistant to impact and chemicals. It is an amorphous and transparent thermoplastic polymer. Depending on its usage, the amount of acrylonitrile varies between 15-35%. Excess acrylonitrile increases the hardness of the product, its resistance to heat and chemicals, and increases its mechanical properties. It contains between 20-30% acrylonitrile. Increasing the amount of acrylonitrile increases the resistance of the copolymer to heat, impact and chemicals, but reduces its moulding property.

Polymethyl methacrylate have high light transmittance, long life, high resistance to ultraviolet rays and weather conditions, can be produced in the desired color and its surface is very hard. As well (it is) as 100% recyclable.

The shapes of valves made from the materials used in the study are given in Fig. 2 (b), (c), (d). It is known from both literature and experience that the mechanical properties of the valve made of brass (a) material are superior to the other three materials. For this reason, the tests were not applied to the brass material, but the appearance information of the valve was shared from the brass material mentioned in the study.

Some properties of the valves used in the experiment and produced in the plastic injection molding machine are given in Table 1.

Table 1. Some properties of materials used in the experiment [10]

Property	unit	SAN	PA66	PMMA	Method
Physical					
Density	g/cm^3	1.08	1.37	1.19	ISO 1183
Water absorption (Equilibrium)	%	0.20	1.9	0.30	ISO 62
Hardness					
Rockwell hardness (M-Scale)	MPa	83	120	97	ASTM D785
Ball indentation hardness (H 961/30)	MPa	165	270	180	ISO 2039-1
Mechanical					
Tensile stress (Yield, 23 °C)	MPa	75.0	200	70.0	ISO 527-2
Tensile strain (break, 23 °C)	%	3.0	3.0	6.0	ISO 527-2
Flexural stress	MPa	125	280	103	ISO 178
Impact					
Charpy notched impact strength (23 °C)	kJ/m^2	2.0	12	2.0	ISO 179
Charpy unnotched impact strength	kJ/m^2	18	80	11	ISO 179
Thermal					
0.45 MPa, Unannealed	°C	100	261	103	ISO 75-2/B
1.8 MPa, Soft annealing	°C	88.0	253	100	ISO 75-2/A
CLTE					
Flow	cm/cm/°C	7.0E-5	2.2E-5	6.5E-5	ISO 11359-2

Strain gauge was glued to the surfaces of the valves to accurately measure the expansion amounts of the three valves. In order to determine the expansion amounts in two directions, the strain gauge was applied at an angle of 45^0 with the surface of the valve (Fig. 3 a).
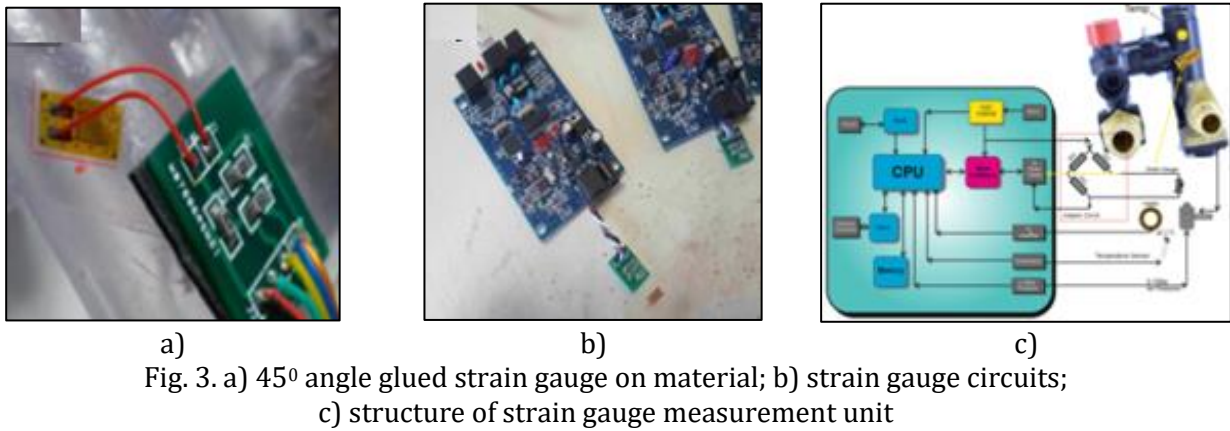

Fig. 3. a) 45^0 angle glued strain gauge on material; b) strain gauge circuits;
c) structure of strain gauge measurement unit

According to this study, the data from three materials with the help of strain gauge circuits (Fig. 3 b) and strain gauge (Fig. 3 c) presented in the figure above, aiming automatically recording of the data obtained at the same conditions with different air pressures.

Strain is the amount of deformation an object experiences compared to its initial size and shape. Strain is a dimensionless quantity and is often expressed as a percentage. Because the amount of deformation is very small, it is expressed as a micro-strain unit. A microstrain is a millionth unity part of a strain-forming deformation. $\mu\varepsilon$ is used as the acronym for microstrain [11].

In the experimental assembly (Fig. 4 a), air heated to 31 and 51 °C passes through the three-way valve with the help of a compressor, and variable compressed air acts on all valves simultaneously, made of SAN (valve 1), PA66 (valve 2) and PMMA (valve 3).
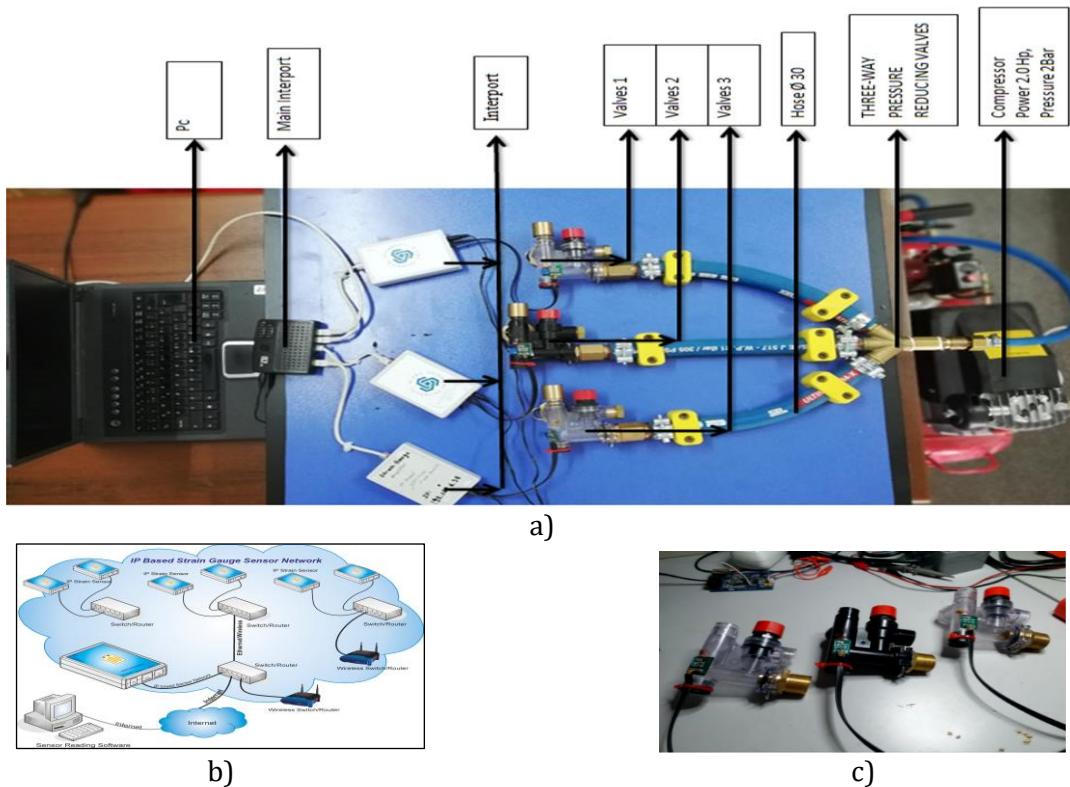

Fig. 4. a) Experimental assembly; b) IoT-SGS software; c) IoT-SGS valves in this study

The degree of hot air applied to the inner surfaces of the valves was measured from the inside of the pipes with the help of a heat meter. Experimental temperature values (31 and 51) were recommended by Pakkens company. The experiment, which started at 0.5 bar, increased by 0.5 bar each time to 2.5 bar and was applied to valves. The applied compressed air is continuously controlled by both the pressure meter in the compressor and the electronic pressure meter in the strain gauge software. Expansion amounts obtained with strain gauge were transferred to main ports using inter ports and then to computer and data was recorded at degree intervals of seconds. Software that allows the transfer of expansion amounts (Fig. 4 b) and strain gauges (Fig. 4 c) attached to the same points of the valve surfaces are given.

3. Results

As a result of applying compressed air applied variably at 0.5, 1.0, 1.5, 2.0 and 2.5 bar to valves at temperatures of 31 and 51 °C, expansion amounts were determined in the experimental assembly.

If the applied air pressure is variable and the air temperature is constant at 31 °C, the amount of expansion depending on the time.

When 0.5 bar pressure was applied at 31 °C, it was determined that the first expansion amount of valve 2 (3383 µε) with the first pressure was lower than other valves, however, valve 1 (3759 µε) and valve 3 (3660 µε) had expansion amounts (Fig. 5). Although the amount of expansion increases as the duration of the applied pressure increases in seconds, no serious change has been detected due to the small amount of applied pressure.
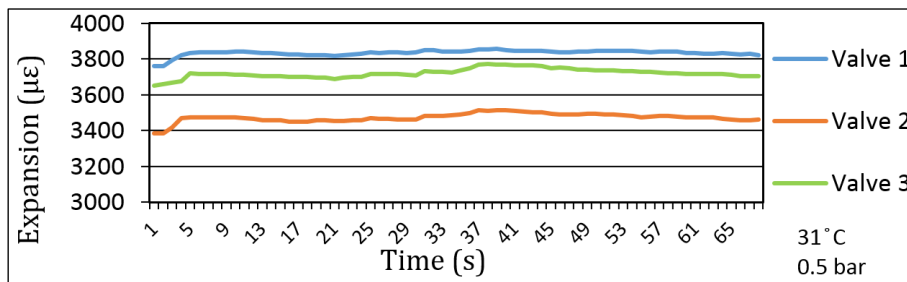

Fig. 5. Expansion amounts of valves at 31 °C and 0.5 bar

When 1.0 bar pressure was applied at 31 °C, the amount of expansion due to the first compressed air of valve 1 and valve 3 was determined to be high valence (Fig. 6). When the application of compressed air continued, no serious change in the amount of expansion was observed.
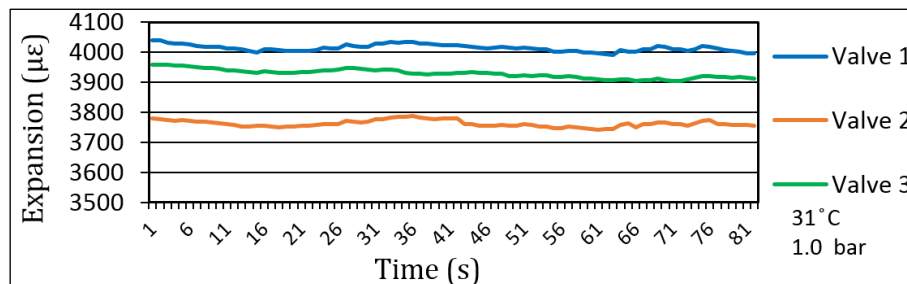

Fig. 6. Expansion amounts of valves at 31 °C and 1.0 bar

At Figure 7, although the expansion amounts of the valves increase at the same rate under a pressure of 1.5 bar at 31 °C, the valve 3 has been observed to expand less than other valves. Valve 1 has been identified as the valve with the most expansion amount.

At 31 °C and 2.0 bar pressure, Fig. 8 shows that the expansion amounts in the valves increase, but the increase in the expansion amount in valve 3 was found to be greater than in other valves.

Under a pressure of 2.5 bar at 31 °C, the increase in the amount of valve 1 expansion is considerable (Fig. 9). In addition, with high pressure, the expansion amount of valve 2 increased more than valve 3.
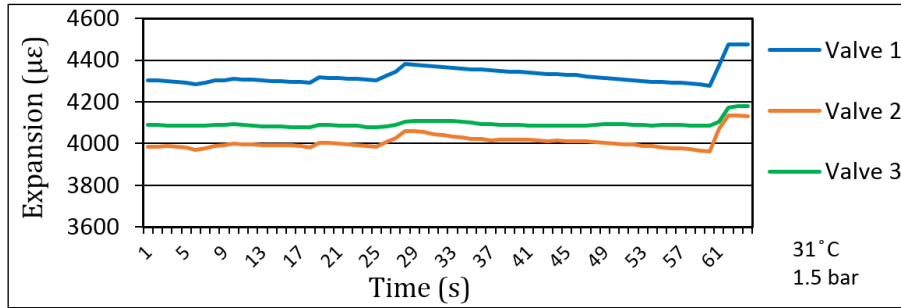
Fig. 7. Expansion amounts of valves at 31 °C and 1.5 bar
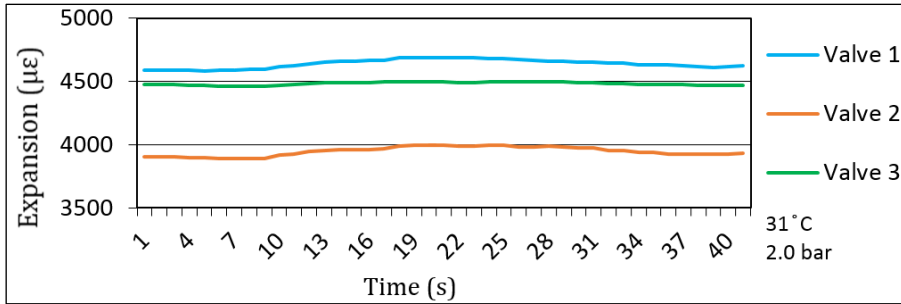

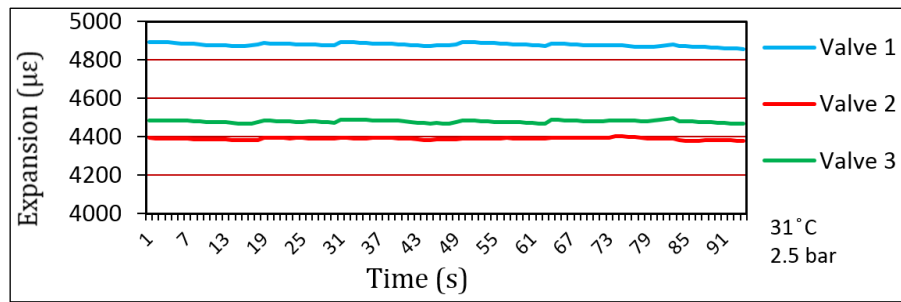Fig. 8. Expansion amounts of valves at 31 °C and 2.0 bar

Fig. 9. Expansion amounts of valves at 31 °C and 2.5 bar

If the applied air pressure is variable and the air temperature is constant at 51 °C, the amount of expansion also depends on the time.

Figure 10 clearly shows, how at 51 °C below 0.5 bar, the expansion amount of valve 1 is the most increased compared to other valves. Valve2 and valve3 have the lowest expansion valence of valve 2, although they have a valence close to each other in the expansion rates.
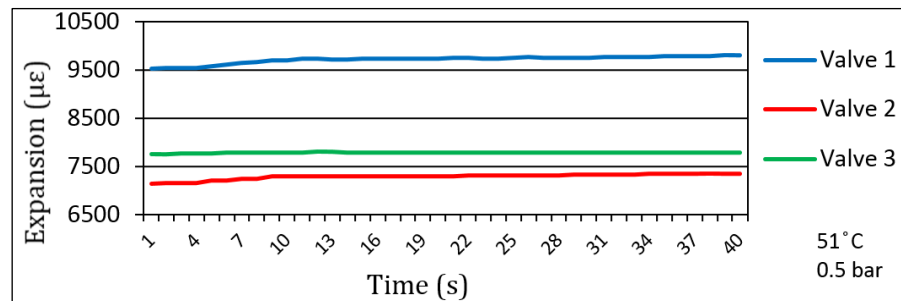

Fig. 10. Expansion amounts of valves at 51 °C and 0.5 bar

Figure 11 represents the behaviour of the three valves with pressure of 1.0 bar and temperature of 51 °C. Valve 1 expansion value is the highest, while the other two valve's values (valve 2 and valve 3) are very similar.

Figure 12 gives a picture of increasing the pressure to 1.5 bar and temperature at 51 °C, the expansion amounts in all valves increase at the same rate, but in time stay constantly.

Figure 13 shows that, when 2.0 bar is applied at 51 °C, valve 1 has the highest amount of expansion, and valve 2 and valve 3 have been shown to increase expansion rates along with increased compressed air.

When 2.5 bar was applied at 51 °C, valve 1 showed a significant expansion compared to other valves, Fig. 14, but valve 2 and valve 3 had close values. Valve 2 had the lowest expansion rate compared to other valves.
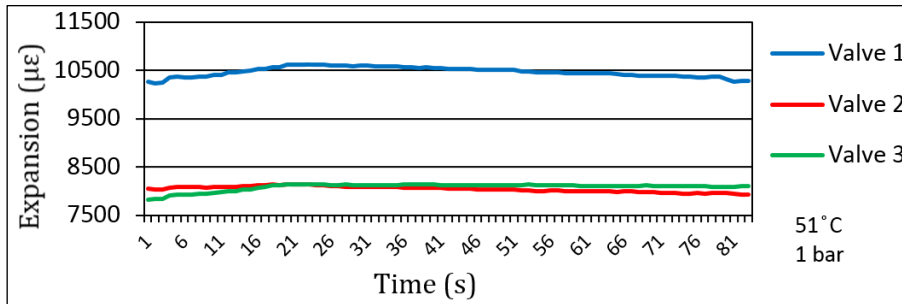
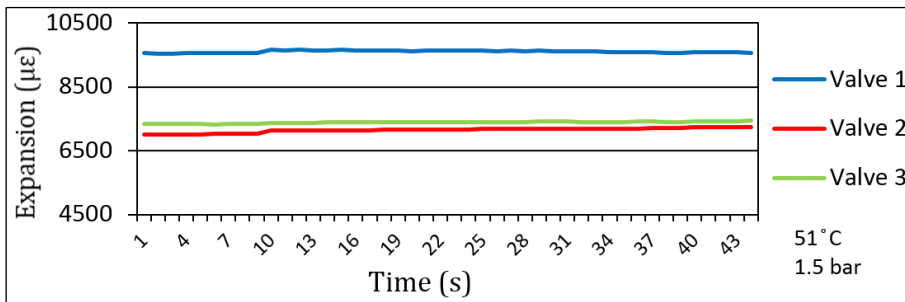Fig. 11. Expansion amounts of valves at 51 °C and 1 bar

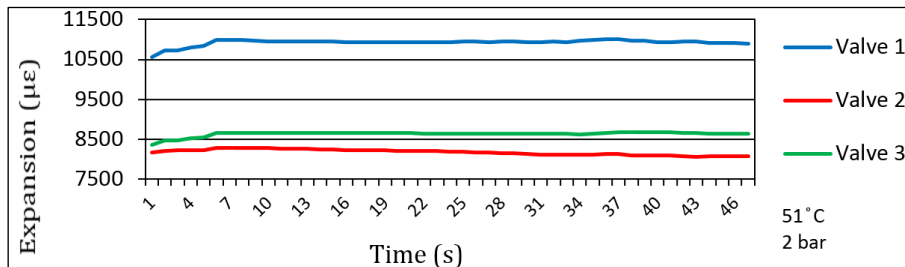Fig. 12. Expansion amounts of valves at 51 °C and 1.5 bar

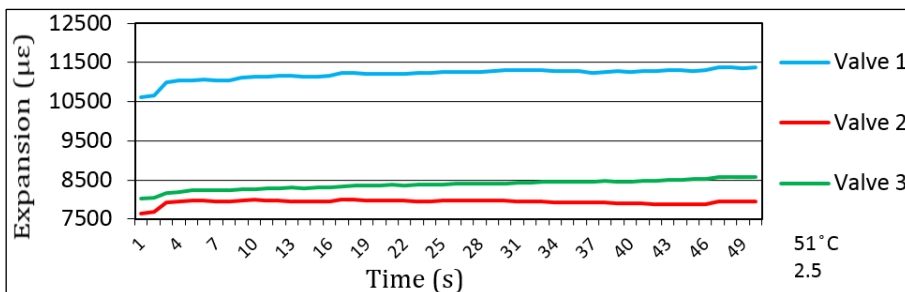Fig. 13. Expansion amounts of valves at 51 °C and 2 bar

Fig. 14. Expansion amounts of valves at 51 °C and 2.5 bar

As a result of the experiments, figures 5-14 is given above in the form of a graph with the amount of expansion obtained with the help of strain gauge glued to the surfaces of the valves degree. Below is the

amount of expansion that occurs when the air pressure applied to the valves at 31 and 51 °C is increased from 0.5 bar to 2.5 bar.

Valve 3 (3760 με) has been found to have the highest amount of expansion, while valve 2 (3418 με) has the lowest amount of expansion when the compressed air is between 0.5 bar and 2.5 bar and is applied at 31 °C, see Figure 15. The amount of pressure was increased up to 2.5 bar and it was determined that valve 1 (4867 με), valve 2 (4473 με) and valve 3 (4764 με) had expansion values.
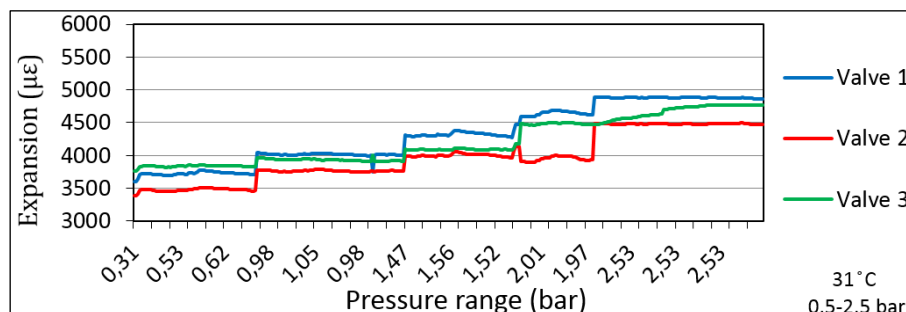

Fig. 15. Expansion amount of valves from 0.5 to 2.5 bar at 31 °C

Valve 2 had the lowest (7153 με) initial expansion when compressed air ranging from 0.5 bar to 2.5 bar at 51 °C, while valve 3 (7772 με) expanded less pressure than valve 2 (9544 με), see Figure 16. But with increased temperature and pressure, valve 1 has had a greater amount of expansion compared to other valves.
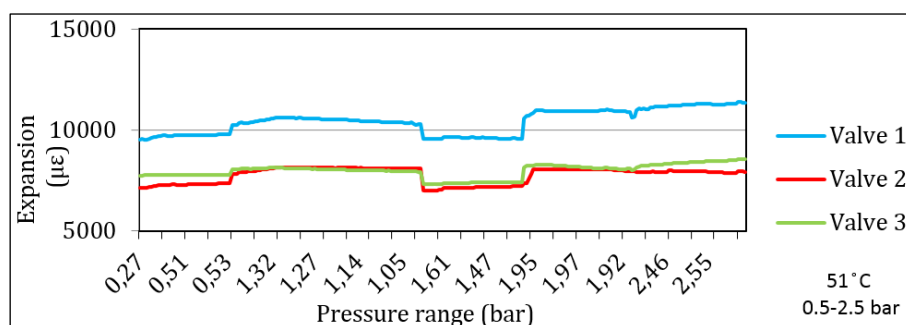

Fig. 16. Expansion amount of valves from 0.5 to 2.5 bar at 51 °C

4. Conclusion

Because of its many advantages over traditional materials, the use of composite materials is increasing every day. In this paper, has been studied if the materials identified are suitable for an alternative to brass material. The research findings resulted in recommendation to the company for the usage of three alternative materials. It was provided that the valves used in the experiment did not require a second process due to the production methods, and the production time took less time compared to the brass material produced by the casting method. For this reason, it has become a necessity for the company to choose a new material.

No significant amount of expansion has been detected materials at 31 °C. But when the temperature rises to 51 °C, it was found that the valve consisting of SAN (valve 1) material has a much greater amount of expansion than other valves.

Valves made from PA66 (valve 2) and PMMA (valve 3) materials were determined to have similar values by means of experiments conducted under the specified conditions. The fact that the applied pressure was not selected too high considering the actual operating conditions was the reason why we could not decipher large differences between the amount of expansion of materials PA66 (valve 2) and PMMA (valve 3) close to one.

Given all the operating conditions of the valve being tested and looking at the data obtained as a result of the experiment, it was recommended that PA66 material can be used by the company instead of the valve produced from brass.

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