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Temperature Data Acquisition for Material Performance of Instrument Panel (IP) in Automotive Applications

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ABSTRACT

The thermal heat inside the interior vehicle is the main concern to provide a comfortable environment for the passengers. Experimental studies were performed in the laboratory and field tests to study the behaviour of the temperature data acquisition in these two conditions. The material characterization analysis used in this work is Differential Scanning Calorimetry (DSC) and Thermogravimetric analysis (TGA). This study is important to investigate the thermal degradation of polymeric materials and determine the material purity used in the automotive components. The temperature measurements were recorded for the selected small component on the Instrument Panel (IP) system that exposed to the hot sun. The results show that the maximum temperature during laboratory and field tests achieved 108.33 °C and 78.2 °C at the IP meter combination, respectively. The maximum temperature achieved for each component on the IP system for both tests has shown that the material can withstand heat resistance during the thermal test in laboratory and field exposure. The temperature difference between these two tests is below 50 %. It was demonstrated that the heat resistance of the material for the IP component is compatible and relevant to automotive applications. The material characterization also revealed that the material used for ABS material on the air outlet and switch centre in the IP system was the virgin material without containing any recycled material. The temperature variations were recorded for the analysis of failure regarding heat factors in Malaysia. The data is necessary to determine whether the temperature in actual service greatly affects the problem of the component. In addition, it would be beneficial for design and material selection for interior automotive applications.

Keywords: *Temperature, Thermal, Material, Instrument Panel, Automotive*

1. INTRODUCTION

This paper describes the design of the thermal test and temperature acquisition for material performance on the P321A Instrument Panel (IP) component for the PROTON vehicle. An Instrument Panel (also called a dashboard) is a control panel located directly in front of a vehicle's driver and front passenger, displaying instrumentation and controls for the vehicle's operation. This IP system contains other sub-component such as glove box, air outlet, center switch and meter combination. Nowadays, the vehicle's interior is becoming one of the most important buying criteria for the customer. The features of the IP should have an aesthetic value, elegant and user-friendly interfaces. Therefore, the durability and appearance of the IP material must be able to withstand the temperature exposure during the application in actual service.

Due to the hot weather in Malaysia, the IP material in the cabin vehicle must be able to withstand these conditions. The temperature inside the vehicle cabin is a vital factor to provide a comfortable condition to the occupants. Several factors that influence comfort inside the cabin vehicle includes, air temperature, relative humidity, temperature, and air velocity [1, 2]. Thus, the amount of heat received by different components at the IP panel is not the same. This variation causes pressure differences in the cabin vehicle, different locations, and material properties of the component. Many car users have faced a hot interior environment after a certain hour of parking in open spaces or unshaded parking areas. The heat under such parking conditions causes the car cabin and interior temperature reach between 35-80°C [3,4].

The aggregation of thermal energy in the cabin vehicle at elevated temperature would cause the degradation of the plastic components and even can emit toxic chemicals to the occupants [4]. This phenomenon may shorten the life span of the various components in the interior vehicle and be hazardous to the occupant. To avoid this problem, the material composition of the plastic part must contain the mineral filler or nucleating agent to increase the heat deflection temperature of the material. Due to this, the previous study has conducted several works in the effort to improve the efficiency and thermal comfort in the cabin vehicle including transforming the heat in the cabin into other forms of energy such as electricity [4], modifying the air-outlet using spanwise inlet vents [5], monitoring the temperature, gas level in the cabin using smartphone [6], solar PV powered ventilation system [7] and portable car-cooling system [8]. These works demonstrated the importance of thermal comfort in the cabin vehicle to the occupants.

Previous research by Mansor et al., [9] demonstrated that the trapped and accumulated heat cause the temperature in the cabin vehicle environment has reached between 36 and 50 °C. The behaviour of the cabin vehicle temperature can achieve until 60 °C when the idle car is exposed to direct sunlight. Helian et al., [10] revealed that the opening window gap and air conditioning can provide a comfortable thermal environment in a car passenger compartment in summer in China. In the process of driving, when all windows were opened, the average temperature decline of a component in car passenger compartment was 11°C and the average air temperature in the car passenger compartment was reduced by about 12°C. When the air conditioning system was opened, the average components' temperature dropped about 12°C and average air temperature decline in the car passenger compartment was about 14°C. Previous researcher by Olisa et al. [10] conducted the thermal test as the car is parked under the hot sun in Nigeria. Based on the result it is found that the maximum temperature achieved at the instrument panel is 72.4 °C and 56.20 °C by closing the window glass and opening the window glass, respectively.

Aljubury et al., [3] showed that the interior air temperature in an unshaded parked car in a hot climate such as Baghdad, reach 70 °C and dashboard temperature can approach 100 °C. In the case of using the cardboard car shade behind the car windshield reduced the dashboard temperature but does not reduce the air temperature inside a parked car. According to Al-Kayiem et al., [11] found that the dashboard contributes to the main sources of convection heat transfer to the cabin vehicle environment. The temperature accumulation is focusing more on the Instrument Panel. However, the temperature in the cabin vehicle was reduced by about 27% when the sunshade was installed underneath the front windshield.

There are several works conducted on the thermal comfort inside of vehicles in the scientific literature, but the number of studies which focus on analysing the temperature data acquisition on the IP component is just a few. Other than that, the assessment of the IP component between laboratory and field test when the car is moving has yet to be explored. No investigation has thoroughly been undertaken to produce significant links between the maximum temperature achieved during laboratory and field tests. It is also to investigate the material purity for Acrylonitrile Butadiene Styrene (ABS) used in the air outlet and switch centre in the IP system. This is to ensure the components part can withstand the heat load during laboratory test and field test. The objective of this study is focused to obtain the maximum temperature achieved on the surface component of the IP and study the correlation of the maximum temperature achieved between laboratory and field tests.

2. MATERIALS AND METHODS

This work consists of two experimental works conducted in the laboratory and field tests. The vehicle used in this work was a PROTON vehicle (P321A model). The first experiment was conducted under a temperature-controlled chamber in the material laboratory, PROTON. Then, the material characterization analysis was conducted using Differential Scanning Calorimetry (DSC) and Thermogravimetric analysis (TGA). The purpose of the analysis was to ensure the purity of the material in the automotive components especially for the Acrylonitrile Butadiene Styrene (ABS) material. This is because this material is the highest usage in the IP systems. The second experiment was carried out to support the experimental result in the laboratory and to collect the temperature acquisition in actual weathering. The thermal test is designed and developed to determine the resistance of the IP components to withstand the temperature and humidity changes that would generate stresses in the material favouring the appearance of cracks, breaks and dimensional changes. There are a couple of ways a temperature change can damage the components. It might be caused by the break of chemical bonds, scission polymer changes, alter the local accumulation of elements and cracks. A list of the raw materials and heat deflection temperature for each component on the P321A IP system are shown in Table 1.

2.1. Thermal Test in the Laboratory Condition (Static)

The components were conditioned in a controlled atmosphere of 23 ± 2°C and 50 ± 5% relative humidity for more than 24 hours before testing. This method is important to bring the material into equilibrium or a steady state. Then, the component was installed in complete assembly form and mounted on a jig fixture to get accurate mounting points and accurate measurement dimensions. The visual inspection of the IP components was conducted before the test commenced.

The complete component installation was placed in a controlled temperature environmental chamber. The thermocouples were installed on the surface component as listed in Table 1. The tip of the thermocouple must be securely fixed on the surface of the component by using an instant adhesive (infrared-reflective tape). The purpose of the thermocouple was to monitor and record the temperature achieved during the experiment. The temperature data logging is used in this experiment to record the temperature achieved on the surface components. To simulate the actual conditions in the car parked under the hot sun, the infrared lamp is installed in the upper area of the IP system to increase the surface temperature of the related component to 110 °C. The distance between the infrared lamp and IP assembly is approximately 1 meter.

The temperature achieved on the component surface is recorded using a data logger to obtain the temperature performance during the experiment. The block diagram of the heat cycle test in the laboratory condition is illustrated in Figure 1. Once the test setup is completed, the test commenced with the test cycle as shown in Figure 2. One cycle consists of 24 hours and is set to run for a total of 3 cycles. Daily inspection is conducted only for visual observation to detect any failure at the earlier stage.

Table 1 List of raw materials for each component on the P321A IP system

No	Component	Component's Function	Material used	Heat deflection temperature
1	Instrument panel (top surface)	To cover the top surface of the IP area	Polypropylene (PP) + talc 20 + Ethylene propylene diene monomer (EPDM)	142.4 °C
2	Air outlet (passenger side)	The adjuster lever to change direction of the air conditioner flow (passenger side on IP)	Acrylonitrile Butadiene Styrene (ABS)	128 °C
3	Glove box	The compartment built into the IP to store important document and items	Polypropylene (PP) + talc 20	118 °C
4	Centre air outlet	The adjuster lever to change direction of the air conditioner flow (center area on IP)	Acrylonitrile Butadiene Styrene (ABS)	128°C
5	Air outlet (driver side)	The adjuster lever to change direction of the air conditioner flow (driver side on IP)	Acrylonitrile Butadiene Styrene (ABS)	128 °C
6	Top surface cover meter combination	The upper part to cover the meter combination	Polycarbonate (PC)/ Acrylonitrile Butadiene Styrene (ABS)	130 °C
7	Center switch	The center part on the IP consists of fog lights button, rear window demister and hazard warning lights button.	Acrylonitrile Butadiene Styrene (ABS)	128 °C

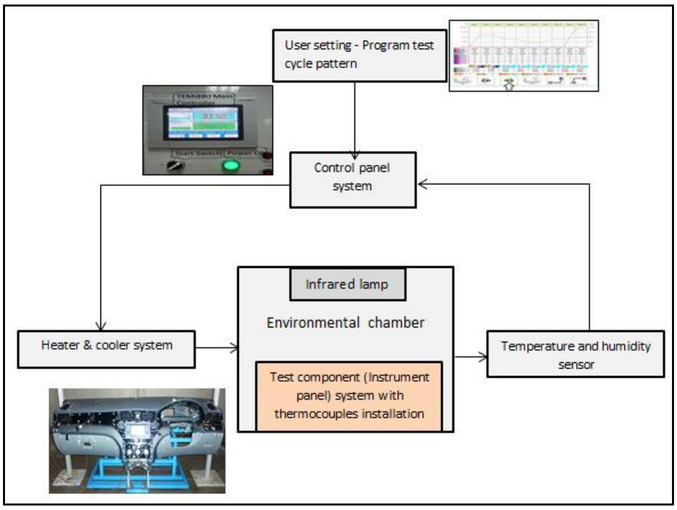

Figure 1. Block diagram of the heat cycle test in the laboratory condition.

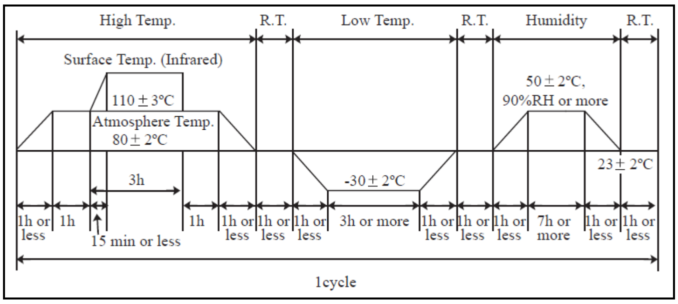

Figure 2. Hot, cold and humidity test cycle (1 cycle).

2.2. Material Characterization Analysis

In this work, the ABS material has been selected for characterization analysis as the majorities of the component in IP system use this type of material such as switch center and air outlets (passenger side, center and driver side). ABS material is an amorphous polymer which made up of three monomers; acrylonitrile, butadiene and styrene. Two specimens have been chosen for this analysis; tested component taken from the heat cycle test and virgin component taken from the production line supplied by vendor. The material characterization techniques were conducted to investigate the thermal degradation of polymeric materials which is Fourier Transform Infrared Spectroscopy (FTIR), Differential Scanning Calorimetry (DSC) and Thermogravimetric analysis (TGA).

Polymeric materials typically undergo irreversible chemical and physical changes when exposed to high temperatures for extended periods of time. Thermal decomposition is the process to describe how heat causes chemical breakdown. The majority of the degradation processes in polymeric materials are accelerated by higher temperatures and there is a potential of mechanical property loss, such as a decline in stiffness and strength. In this mode, the polymer's long-chain backbone's constituent parts are susceptible to breaking (a process known as chain scission) and interacting with one another to alter the polymer's characteristics. Since heat is needed to break chemical bonds in the substance that is decomposing, the reaction is typically endothermic. Decomposition may initiate other chemical reactions if it is sufficiently exothermic. The particular materials produced will differ based on the colorants and additives, temperature, exposure duration, and other environmental variables.

2.2.1 Fourier Transform Infrared Spectroscopy (FTIR)

This technique is used to determine the materials molecular and structure. It uses infrared light to scan test samples and observe chemical properties. This technique measures the absorption of infrared radiation by the sample material versus wavelength. In PROTON, normally this technique is used to obtain an infrared spectrum of material. It is used to determine and compare the pattern of the graph with other materials if, the components are suspected of using different or wrong materials.

2.2.2 Differential Scanning Calorimetry (DSC)

This technique is used to investigate the response of the polymer material to heating and measure the enthalpy changes due to changes in the physical and chemical properties of a material as a function of temperature or time. In this work, this technique is used to obtain the glass transition temperature of the component (finish product). Then, the result was compared with the heat deflection temperature of raw materials to determine the component uses the correct material as declared by the supplier.

2.2.3 Thermogravimetric Analysis (TGA)

This technique is used to characterize materials by measuring weight changes as a function of temperature. The weight changes of polymeric materials can be caused by decomposition and oxidation reactions as well as physical processes such as sublimation, vaporization, and desorption. In this study, this technique is used to detect traces of additional compound or additives.

2.3 Thermal Test in the Field Condition (Moving Car)

The setup is similar to the experimental works in the laboratory condition, but this work is conducted using a complete build-up vehicle and moving vehicle. This work was carried out with a total trip of 3 days. This car has been driven towards South Malaysia from PROTON Shah Alam to Johor Bharu and then back to the origin. The road choice is not so important since the main purpose of this activity is only to collect the random temperature data in Malaysia while the car is moving. The inspection of the vehicle was conducted to check for any defects or functional problems before running the vehicle. The thermocouple (transducer type) was attached to the components to record and monitor the temperature acquisition. The thermocouple was installed on a component similar to the thermal test in section 2.1.

In this work, the vehicle speed was about 80 to 100 km/hour and the mileage is about 1025.2 km. Details of routes during this activity is shown in Table 2. . The outside temperature and humidity were measured using a hygrometer and recorded at each checkpoint. The temperature data acquisition on the component was recorded using Yokogawa Hybrid Recorder HR 2300 system connected to a laptop computer. All data are acquired in a moving car with air-conditioned at a set temperature of 18 °C to 25 °C. The total passenger inside each vehicle is 2 persons. The schematic diagram of the test setup during a thermal test in field test is shown in Figure 3. The temperature acquisition was recorded every hour starting from 10 am until 9 pm. The block diagram of the temperature data acquisition for the thermal test in the field test is shown in Figure 4.

Table 2 Details of routes of the moving vehicle from Proton Shah Alam to Johor Bharu

Route	Day	Time	Destinations	Mileage (km)
A	Day 1	11.30 am	PROTON Shah Alam – Pedas Linggi Negeri Sembilan	98.3
B		12.46 pm	Pedas Linggi – Pagoh	196.4
C		2.30 pm	Pagoh – Kluang	282
D		4 pm	Kluang – Mersing	367.2
E		6 pm	Mersing – Kota Tinggi	415.3
F		9.30 pm	Kota Tinggi – Hotel Johor Bharu	506.1
G	Day 2	10 am	Hotel Johor Bharu – Danga Bay JB	516.4
H		12.30 pm	Danga Bay JB - Pontian	600
I		3.50 pm	Pontian - Parit Jawa Muar	700.4
J		8.43 pm	Parit Jawa Muar – Klebang, Melaka	785.2
K		9.53 pm	Klebang, Melaka – Dataran Pahlawan Melaka	795.9
L	Day 3	2.11 pm	Dataran Pahlawan Melaka – Pantai Port Dickson, Negeri 9	932.2

M		7.16 pm	Pantai Port Dickson, Negeri 9- Proton Shah Alam	1025.2

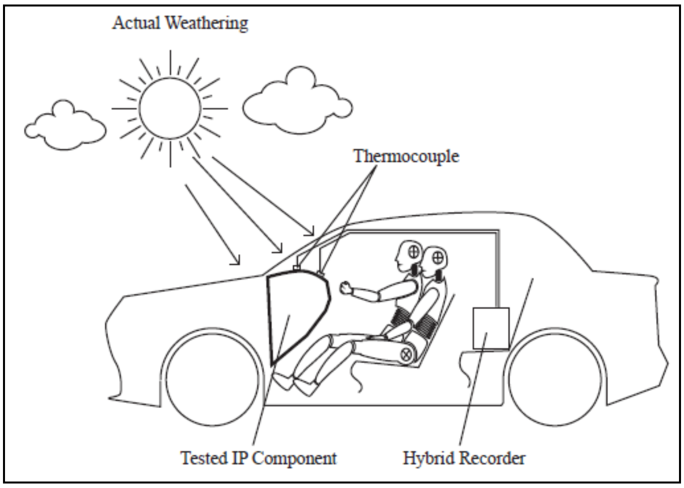

Figure 3. Schematic diagram of the test setup during thermal test in field test.

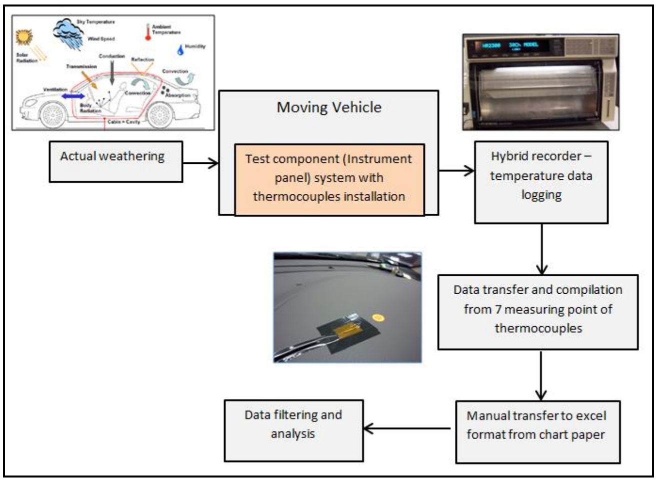

Figure 4. Block diagram for temperature data acquisition for thermal test in field test.

3. RESULTS AND DISCUSSION

3.1. Material Characterization Analysis

3.1.1 Fourier Transform Infrared Spectroscopy (FTIR)

The result of the FTIR spectrum that have been done for P321A air outlet and switch center (ABS material) of tested and virgin components are shown in Figure 5(a) and 5(b), respectively. From these two graphs, the FTIR spectrum was compared to determine whether the material used is similar between tested and virgin component. Based on the result, both components have shown almost the similar spectrum in the fingerprint and functional group region. From here, it is demonstrated that both components are using the similar material grade of ABS 777D. It can be seen that the spectrum contains C-H molecular structure at the functional group region which match with ABS chemical formula (C8H8.C4H6.C3H3N)n. However, there is a formation of carbonyl group (C=O) for tested components and this behavior might be contributed from the thermo-oxidative degradation after the thermal test.

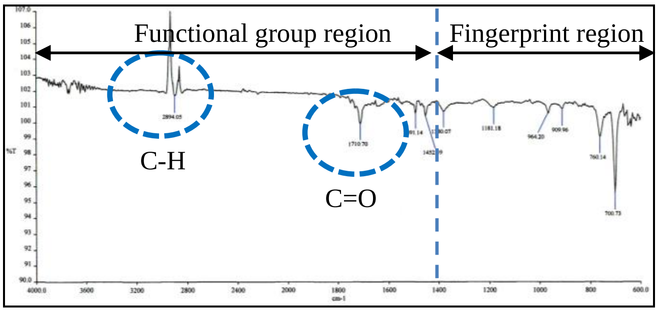

Figure 5 (a). FTIR spectrum for P321A air outlet and switch center (ABS material) for tested component.

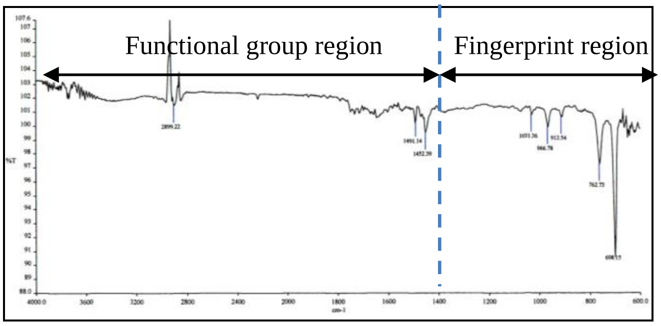

Figure 5 (b) FTIR spectrum for P321A air outlet and switch center (ABS material) for virgin component.

3.1.2 Differential Scanning Calorimetry (DSC) Result

The result of the DSC curve that has been done for the air outlet and switch center (ABS material) is shown in Figure 6. When comparing the DSC curve between tested and virgin component, the material obtained almost the same glass transition temperature with value of 110.39 °C and 108.4 °C, respectively. This result also indicates that both materials are below the heat deflection temperature (128 °C). However, it can be seen the slight increment of about 1.83 % for tested component compared to virgin component. This phenomenon might be due to the polymer molecular has changed after the thermal test.

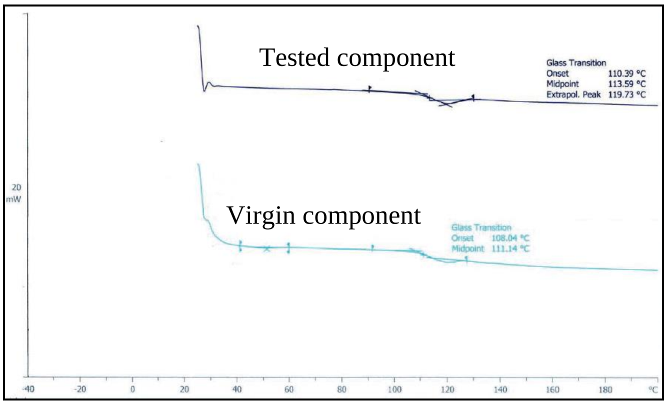

Figure 6. DSC curve for the air outlet and switch center (ABS material) for tested and virgin component.

3.1.3 Thermogravimetric Analysis (TGA) Result

In this study, this technique is used to detect traces of additional compound/additives. The result of the TGA analysis that for the air outlet and switch center (ABS material) using tested and virgin components is shown in Figures 7 (a) and (b), respectively. From here, the result has been compared to determine if the material used for tested and virgin component is the same. Based on both graphs, the mass change for tested components is 93.73 %, while for virgin component is 95.21%. It was revealed that both components are using the similar material grade without detection of any recycled material. If the material contains recycled material, the value of the mass change might increase due to presence of foreign materials.

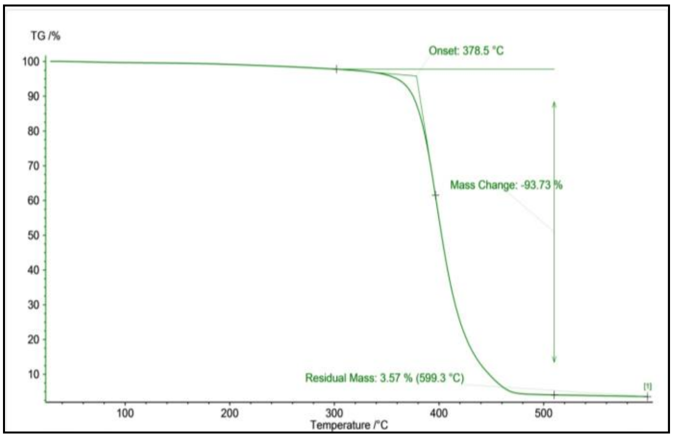

Figure 7(a). TGA graph for the air outlet and switch center (ABS material) for tested component.

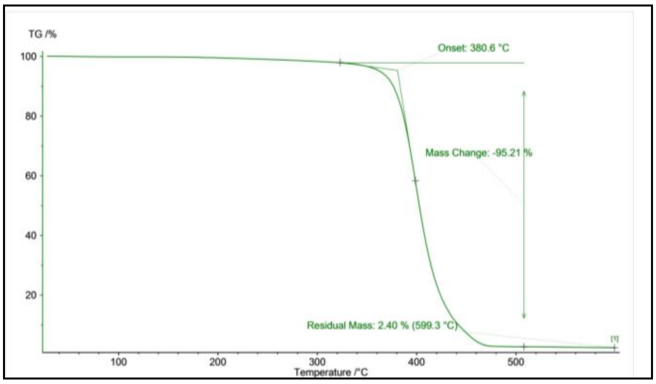

Figure 7(b). TGA graph for the air outlet and switch center (ABS material) for virgin component

Overall, the material characterization analysis showed that the material used for tested and virgin components are the same material without detecting any recycled material. It demonstrates that the components for the air outlet and switch center system have met the product requirement.

3.2 Thermal Test in the Laboratory Condition

Based on the results, all the components of IP system exhibited no severe deformation and defects after the experimental works. The maximum temperature achieved on the component is also recorded and presented in Figures 8 and 9.

Figure 8 shows the highest maximum temperature achieved on the cover meter combination and IP top surface with a temperature of 108.3 °C and 98 °C, respectively. Meanwhile, the lowest maximum temperature achieved on the glove box with 82.8 °C. This is due to the component being located at the lowest position in the IP system. For another component, the air outlet at the passenger side and centre air outlet exhibited the maximum temperature of 88.6°C and 89.6 °C, respectively. Other than that, the air outlet at the driver's side achieved the maximum temperature of 92.2 °C and the centre switch of 89.2 °C. From all this data, it can be demonstrated that the maximum temperature achieved at each component is below the maximum surface temperature of 110 ± 3 °C and above the atmosphere temperature of 80 ±2 °C.

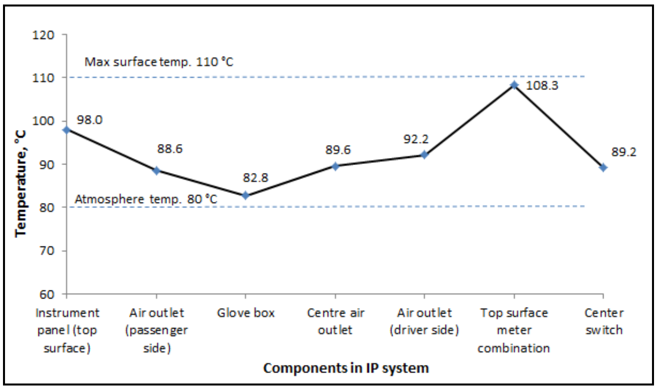

Figure 8. Maximum temperature achieved at component on IP system during infrared exposure heat cycle test.

3.3 Thermal Test in Field Test

Based on the result from a thermal test in the field test, the component on the P321A IP system has passed the thermal test requirement with no severe deformation observed after the test. The functional performance of the glove box, switch center and air outlet also remain in a good condition after the test. The details of the temperature achieved inside the car and weather conditions of the moving vehicle were tabulated in Table 3.

Based on the graph in Figure 9, the highest maximum temperature on the IP system is the IP top surface and IP cover meter combination with temperature values of 80.1 ° C and 78.2 °C, respectively. This result could be explained by the position of these components which are located in the upper area of the IP system. For other components, the maximum temperatures are between 48 °C and 70.3 °C. These temperatures are still below the temperature limit of the PROTON specification (surface temperature of 110°C and atmosphere temperature of 80 °C). It was also below the temperature obtained from the heat cycle test in the laboratory with the temperature ranging between 48 °C and 80.1 °C.

On the other hand, the lowest minimum temperature on the IP system was found in all air outlet areas (air outlet at the passenger side, center and driver side) with a temperature value of 10.2 °C, 10.8 °C and 11.5 °C, respectively. This is correlated well with the source of the air conditioning system that starts from this component, thus contributing to the lowest temperature in this area. Meanwhile, the minimum temperature achieved in other components is from 13 °C to 21 °C.

Table 3 Details of temperature inside the car and weather conditions of the moving vehicle from Proton Shah Alam to Johor Bharu

Route	Day	Temp. inside the car (°C)	Weather condition, °C (temp. outside the car)	Weather condition, % (humidity outside the car)
A	Day 1	25.3	28.4 (cloudy)	41
B		37.9	33.0 (sunny)	51
C		32.5	31.9 (slightly cloudy)	76
D		29.3	31.9(rainy)	68
E		25.9	26.8(rainy)	71
F		28.6	29.0(rainy)	69
G	Day 2	31.1	29.9 (slightly cloudy)	52
H		35.3	34.2 (sunny)	38
I		33.9	32.9 (sunny)	51
J		27.5	27.9 (night)	57
K		25.5	26.4 (night)	47
L	Day 3	34.9	39.0 (sunny)	40
M		28.8	30.9 (sunny)	56

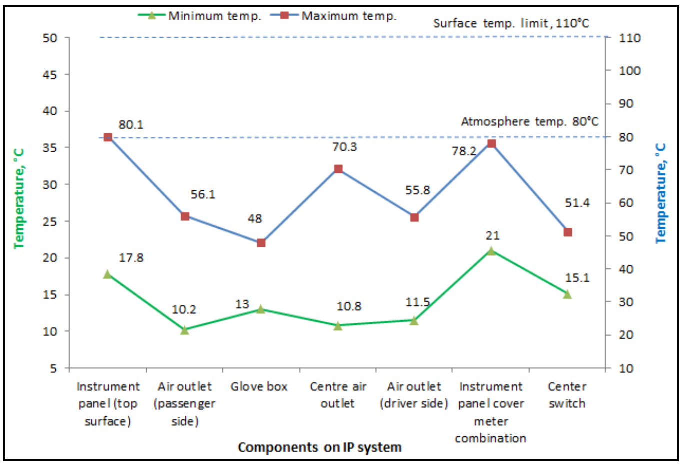

Figure 9. Maximum and minimum temperature achieved at each component on IP system during thermal test in field test (actual service).

3.4 Assessment and Discussion of Thermal Test Between Laboratory and Field Test

The maximum temperature achieved for each component in the IP system between laboratory test and field test was compared and presented in Figure 10. Based on the figure, the maximum temperature was obtained in the range of 82.8 °C to 108.3 °C for the thermal test in laboratory conditions. Meanwhile, for the thermal test in field conditions, the maximum temperature of the components is between 48 °C and 80.1°C. Both temperatures had some fluctuation due to different positions of the component located in the upper or lower area in the IP system. The maximum temperature was achieved at 108.3 °C for the IP meter combination during the laboratory test, while 80.1 °C for IP top surface during the field test. However, both graphs show that the glove box is the component that reaches the lowest temperature during laboratory and field tests with the value of 82.8 °C and 48 °C, respectively.

Overall, it can be seen that the temperature during laboratory tests experienced more consistent values compared to the field test. This is due to the temperature-controlled chamber condition in a laboratory test, while the field test is controlled by natural weathering. Other than that, the maximum temperature achieved during the laboratory test is always higher than the temperature for the field test. This result occurred due to several factors; the component in the laboratory test is exposed directly to the heat environment with a static condition, meanwhile, the component in the field test is conducted using complete vehicle build-up with moving conditions. Other than that, the presence of an air conditioning system during the field test would have changed and reduced the cabin airflow.

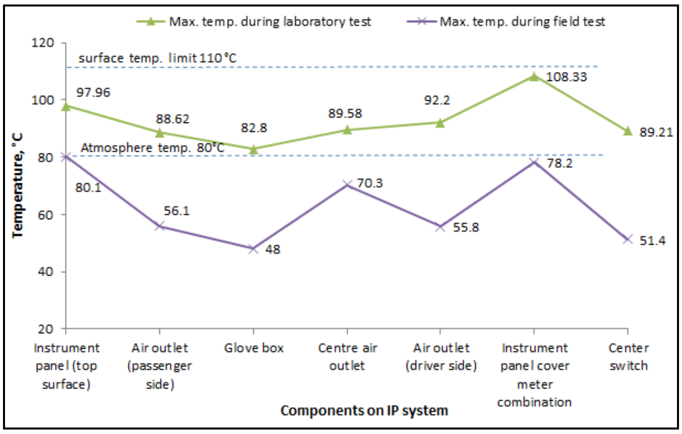

Figure 10. Maximum temperature achieved for each component on IP system during laboratory and field test.

The pie chart in Figure 11 provides information about the difference in temperature in percentage for each component of the IP system between laboratory and field tests. Based on the chart, it can be seen that the difference percentage of the temperature between laboratory and field tests was obtained in the range of 18.2 % to 42.4 %. The highest temperature difference was observed on the center switch with a percentage of 42.4 %. In the meantime, the lowest temperature difference can be observed on IP top surface with a percentage value of 18.2 %. For air outlets on the passenger side, center and driver side, the percentage of temperature differences were 36.7 %, 21.5 % and 39.5 %, respectively. For the rest of the components such as the glove box and IP cover meter combination, the percentage difference was obtained between 27.8 % and 42%, respectively.

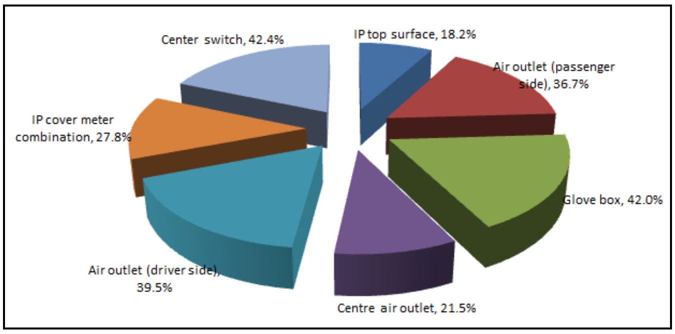

Figure 11. Difference of temperature in percentage for each component on IP system between laboratory and field test.

4. CONCLUSION

The thermal test and temperature acquisition for material performance and evaluation on P321A Instrument Panel (IP) component for PROTON vehicles has been successfully developed. Based on the results and discussions, the following conclusions can be drawn from the present project:

1. The maximum temperature achieved at the IP component is 108.33 °C for the thermal test in the laboratory and 78.2 °C for the field test, both results located at the top surface IP meter combination.
2. The material characterization analysis reveals that the material used was the virgin material without containing any recycled material. It demonstrates that the components for the air outlet and switch center in the IP system have met the product requirement.
3. The material used on the P321A IP system was able to withstand heat resistance exposure without any severe deformation or defects observed after laboratory and field tests. It was revealed that the heat resistance of the material is compatible and relevant to automotive applications.
4. The maximum temperature for the laboratory and field test has been successfully achieved by a temperature difference percentage below 50%. Thus, temperature acquisition has shown a good correlation between laboratory and field tests.

The field test is correlated well with the temperature performance in the laboratory test, as long as the temperature obtained from both tests is below the heat deflection temperature of the material (118 – 142.4°C) and the surface temperature limit of test specification of 110°C.

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