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# Crack Formation Analysis of Return Air Flow Clamping in Air Conditioning using Finite Element Method

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*Abstract*— **In this study, crack formation during assembly and in service of injection molded return air flow clamping unit in the air conditioning system was carried out by using finite element method in couple with mechanical testing including tensile test and fatigue test to investigate the possible cause and ways to remedy such causes. It was found that high level of Von Misses stress closed to the yield strength value of the high impact polystyrene (HIPS) which was a raw material used was formed on the part while the fatigue strength of the specimen was also relatively low. Failure of the clamping unit of the return air flow was possibly caused by the excessive stress in the part which was a result of changing from the typical use of acrylonitrile-butadiene-styrene (ABS) to weaker and more brittle HIPS by the manufacturer. The design of the part should be reviewed to take into account this difference.**

*Index Terms*— **Fatigue strength, Deformation, Injection molding, High impact polystyrene.**

## I. INTRODUCTION

Today, engineering plastics have been used widely and increasingly in many industries for example electronics parts or household objects due to their distinguished features such as light weight, good processability and low cost [1]. The selection of plastics type and their properties are crucial since these could affect the quality and performance of the parts during services. In general, the failures that have been frequently encountered are excessive deformation and premature fracture prior to designed service life[1]. In this study, the failure analysis of the air conditioning's part called "return air flow" as shown in Fig. (1a) which is located at the front of the air conditioning indoor unit and used to control the direction of air flow into the room was carried out. This part contains several snap-type clamping units (Fig. 1b) used for assembling the part to the main indoor unit. In the past, this part was made of acrylonitrile-butadiene-styrene (ABS) by injection moulding process, but recently was changed to high impact polystyrene (HIPS) due to the cost reduction policy. However, the occurrence of visible cracks in the clamping units during part assembly which consisted of bending the clamp out approximately 4.5-5.0 mm to snap into the counter holes was observed. Furthermore, several cracks also developed later during movement and vibration in services although the cracks were not observed during such assembly process. This resulted in the increase in numbers of defective parts that were needed to be replaced and claimed which raised the concern in quality of the manufacturer. Finite element analysis and mechanical testing including tensile test and fatigue test were thus carried out in this study to investigate the possible cause and ways to remedy such causes.

(a)

(b)

Fig. 1. Images of a) return air flow part and b) the clamping unit.

## II. EXPERIMENTAL AND METHOD

### A. Specimen Preparation

Raw material used in this study was high impact polystyrene (STYRON A-TECH 1180, Dow Chemical Pacific Limited). The specifications are shown in Table I.

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It was injection moulded into return air flow workpiece following the typical conditions of the manufacturer and the specimens (ASTM D638-00 type II for tensile test and ASTM E606-04 for fatigue test) were then machined from the injection molded part using a CNC milling machine (EMCO PC MILL 50). All the machining surfaces were polished by a fine abrasive paper to remove the machining marks.

TABLE I
Specifications of HIPS grade STYRON A-TECH 1180 [2].

| Properties: Unit | Values (standard) |
|---|---|
| Modulus of elasticity (*E*) : MPa | 1900-2500 (ASTM D638) |
| Yield Tensile Strength : MPa | 34 (ASTM D638) |
| Ultimate Tensile Strength : MPa | 31 (ASTM D638) |
| Elongation : % | 25-55 (ASTM D638) |
| Poisson's Ratio | 0.38 (ASTM D638) |
| Density : g/cm$^3$ | 1.04-1.05 (ASTM D792) |

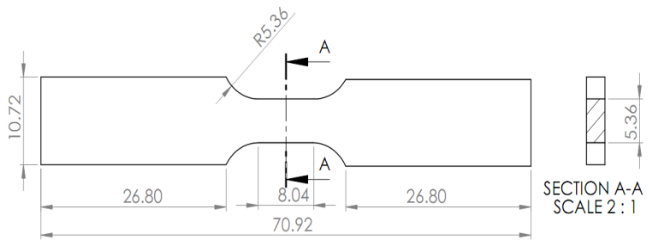


Fig. 2. Drawing of fatigue specimen.

*B. Density*

Density was performed according to ASTM D792 using a balance with density kit (Mettler Toledo AG204). All the tests were carried out at 23 °C and the average value were obtained from five replications.

*C. Tensile Testing*

Tensile testing was performed according to ASTM D638 using a universal testing machine (Instron 55R4502) equipped with 25 kN load cell and advanced video extensometer (AVE). All the tests were carried out using a crosshead speed of 5 mm min$^{-1}$ at 23 °C and 50 % RH. [4].

*D. Finite Element Analysis*

CAD image of the clamping unit was created by scanning a real physical part by a coordinate measuring machine (Mitutoyo7106-Beyond CrystaC). Triangular mesh was used and 3D finite element analysis was performed to investigate the stress distribution in the workpiece using MSC PATRAN in static mode. The part was fixed at the base and loads ranging from 1 to 11 N were applied at center of the knob at the end of the clamp to bend the part similarly to the assembly procedure (Fig. 3). The distribution of Von Misses stress and deformation in the part were calculated and used for analysis [5].

*E. Fatigue Testing*

Fatigue testing was carried out using a dynamic testing machine (Instron 8872) at 23 °C and 50 % R.H. The test was conducted under tension-tension mode at the frequency of 5 Hz using a sine waveform. The stress ratio was fixed at 0.2 and the maximum stresses were varied between 31MPa and 8.5 MPa. Tests were done until failure and the number of cycles at each stress level was obtained.

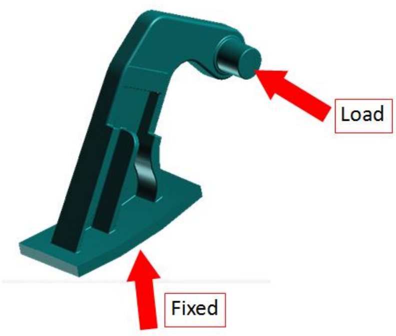


Fig.3. Boundary conditions and the location of applied load in the finite element analysis.

## III. RESULTS AND DISCUSSION

Table II shows the results obtained from tensile test of HIPS specimens. It could be seen that all the values were closed to the specifications as reported by the supplier excepting the elongation and density which were significantly different from the specified values. The lower elongation at break and higher density were found to be caused by the addition of the colorant in the raw materials upon supply. It was previously observed that the use of additives in plastics could alter their properties in different ways depending on the types of additives, types of plastics and the content used [6]. The addition of colorant in this grade of HIPS obviously increased the brittleness of the plastic.

TABLE. II
Mechanical properties of HIPS specimens

| Properties: Unit | Measured Values |
|---|---|
| Modulus of elasticity (*E*) : MPa | 2253±72 |
| Yield Tensile Strength : MPa | 33±1.8 |
| Ultimate Tensile Strength : MPa | 30±1.7 |
| Elongation : % | 5±4 |
| Poisson's Ratio | 0.37±0.032 |
| Density : g/cm$^3$ | 1.32±0.006 |

Finite element analysis as shown in Fig. 4 displays the distribution of the Von Misses stress and displacement in the clamp of the return air flow part. Maximum stress values were similarly found at the upper area of the neck of the part regardless of the applied load, but the values increased with increasing applied load. However, the maximum Von Misses stress in the sample reached the plateau at the applied load of approximately 4-5 N and only slightly increased with further increase in applied load (Fig. 5). These stress values were in the range of 28.8-30.8 MPa which were closed to the yield strength and even greater than the ultimate strength of the HIPS specimens as determined from tensile test. Correspondingly, the displacement of the sample linearly increased with increasing applied load without reaching a plateau limit as observed in Von Misses stress (Fig. 6). This means that when the applied load was lower than 4 N, the sample could withstand the load with only small deformation, but subjecting to high stress in some localized area. Once the load was greater than 4 N, the sample started to plastically deform and could not tolerate the applied load since the stress already reached the yield strength of the materials. At this stage, the sample changed the shape permanently or even produced damages [7]. From the analysis, the sample

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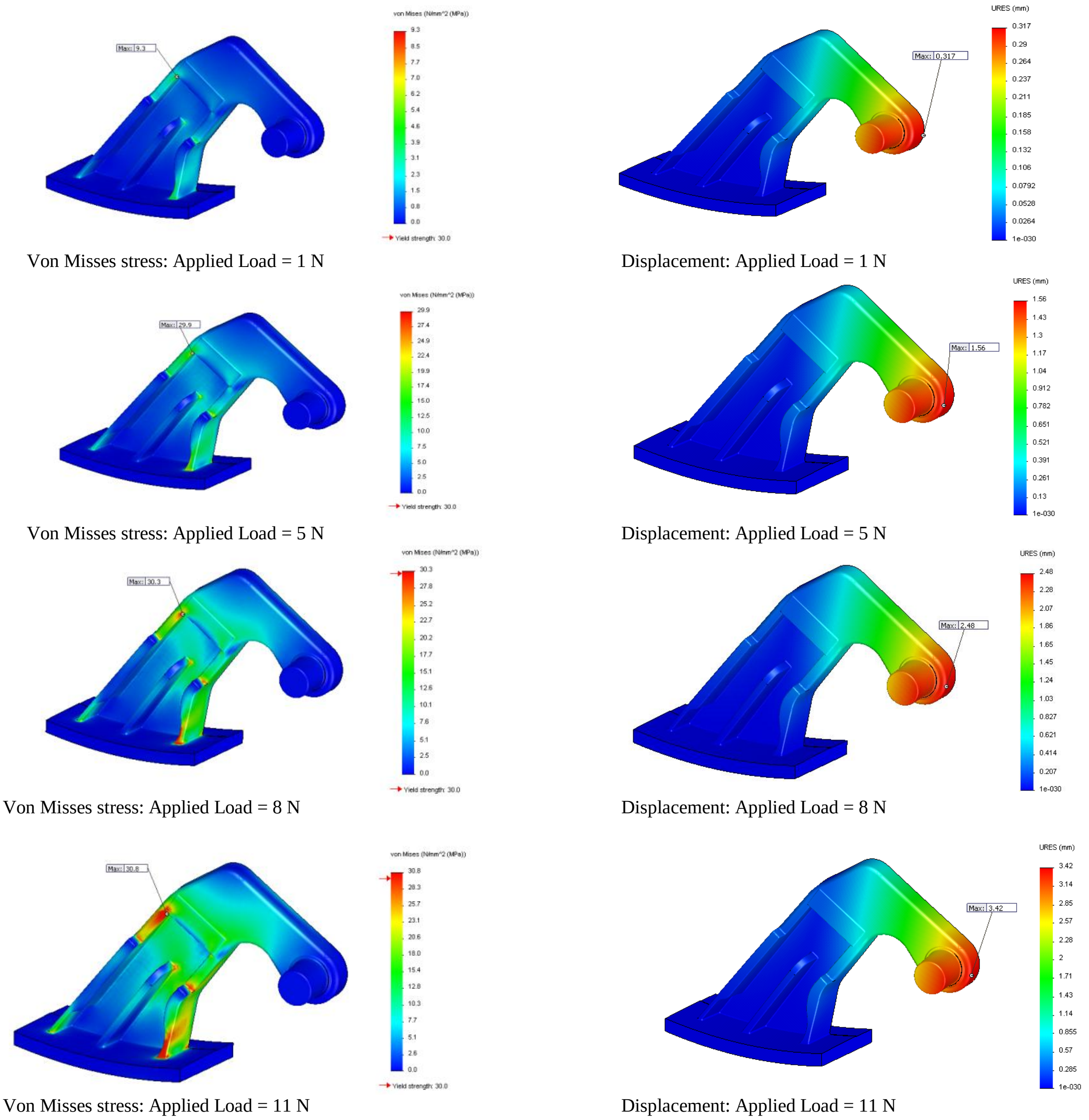
could be bended to just only 1.25 mm under the applied load of 4 N before exhibiting plastic deformation which could cause the damage. This was significantly lower than the bending distance of 4.5-5.0 mm as needed in the actual assembly process and might be the cause why the cracks were observed during assembly of the parts. These low values of bending may be also related to the low values of the elongation at break of the specimens as observed from tensile test. Fig. 7 shows the image of the damage part which contained crack caused by the assembly process. It could be obviously seen that the location of the crack corresponded well with the location of maximum Von Missess stress as seen in FEM analysis. Stress vs. Number of cycle to failure curve (S-N curve) of the specimens under tension-tension fatigue is shown in Fig. 8. No clear endurance limit was found even the stress was as low as 8.5 MPa and low number of cycle, 236,994 cycles, was obtained at this stress level. When subjecting to high level of stress in the vicinity of yield strength as seen in FEM analysis, the cycles to failure of specimens decreased to only 223 cycles. This may correlate to the observation of in-service crack formation of the part even the cracks were not observed during assembly step.

Upon changing from using ABS to HIPS as raw materials for part production, the manufacturer did not review the design to take into account the difference in the mechanical properties of the raw materials. Since the tensile strength and elongation at break of ABS are greater than those of HIPS (Table III), the current design of the return air flow part that used ABS as raw material might not be appropriate for HIPS and the modification of the part design should be taken to justify these differences. In addition, the specifications in the data sheet of the plastics as supplied from the supplier should be verified carefully whether they are the real ones and the test should be carried out to see if there were any differences.



Von Misses stress: Applied Load = 1 N
Displacement: Applied Load = 1 N
Von Misses stress: Applied Load = 5 N
Displacement: Applied Load = 5 N
Von Misses stress: Applied Load = 8 N
Displacement: Applied Load = 8 N
Von Misses stress: Applied Load = 11 N
Displacement: Applied Load = 11 N

Fig.4. Distribution of Von Misses stress and displacement in the samples as obtained from FEM analysis. Arrows indicated the location of maximum value.

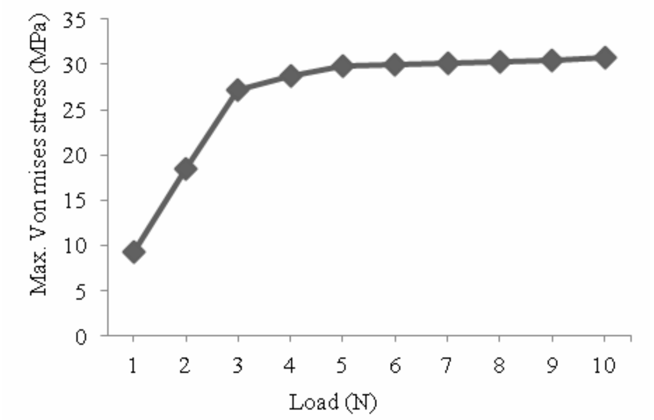



Fig.5. Maximum Von Misses stress vs. applied load as obtained from FEM analysis.

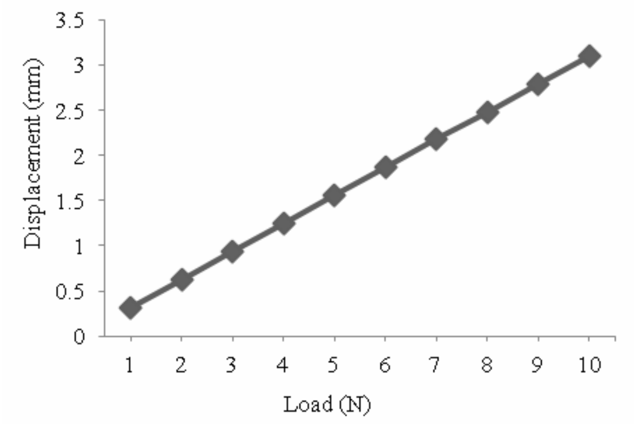



Fig.6. Maximum displacement vs. applied load as obtained from FEM analysis.

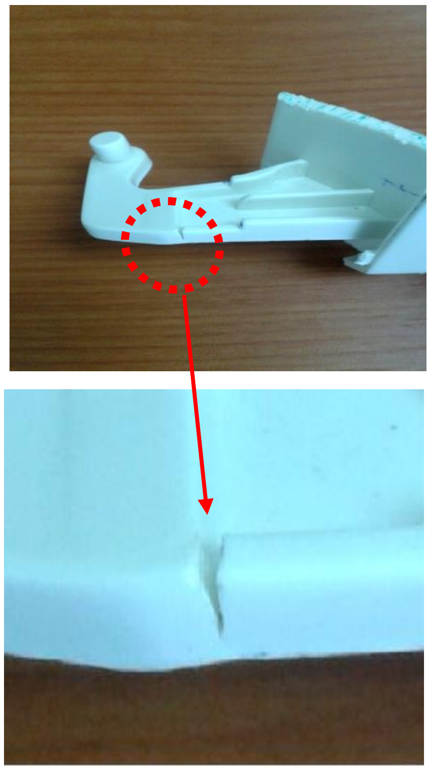


Fig.7. Location of crack as found on the actual part during assembly.

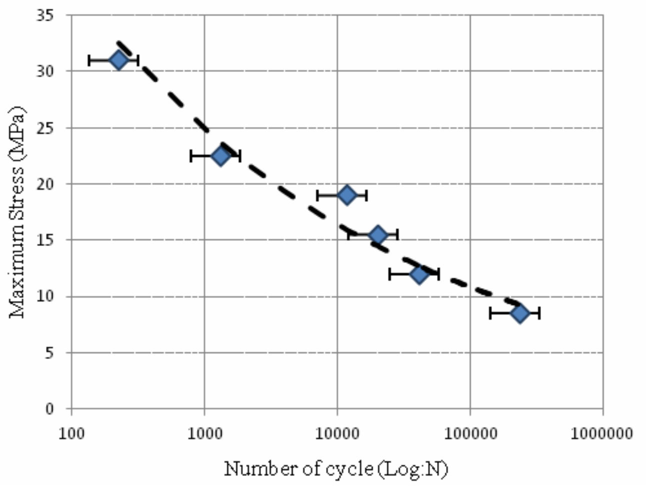



Fig.8. Stress vs. Number of cycle to failure curve of HIPS specimens.

TABLE. III
Specifications of ABS used to produce the old part

| Properties: Unit | Values |
|---|---|
| Modulus of elasticity (*E*) : MPa | 2224 |
| Yield Tensile Strength : MPa | 44.8 |
| Ultimate Tensile Strength : MPa | 31 |
| Elongation : % | 40 |
| Poisson 'Ratio | 0.38 |
| Density : g/cm$^3$ | 1.04 |

## IV. Conclusion

It could be concluded that the failure of the clamping unit of the return air flow was possibly caused by the excessive stress in the part which was a result of changing from stronger and tougher ABS to weaker and more brittle HIPS. The design of the part should be reviewed to take into account this difference.

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