INVESTIGATION OF THE JOINING OF ACRYLIC

BY LOW POWER CO_2 LASER

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ABSTRACT

In the last few decades, the technology of welding has been improved and there are several types of welding technology being invented. Carbon dioxide (CO_2) laser welding is one of the new technologies that have been playing an important role in this era. In this project, the optimum parameter of the welding of acrylic by low power CO_2 laser is studied. Three main parameters are studied in this project which is stand-off distance, welding speed and the number of pass. The power is constant which is 75 Watt. These three main parameters are grouped by using the Taguchi Method in Minitab Software. The grouped parameter is then investigated and the tensile strength and micro-bubble size of each group is tested and recorded in table form. The Analysis of variance (ANOVA) table is prepared and the ranking of each parameter is investigated. Several graphs are plotted in order to find the relationship between the tensile strength and the micro-bubble size. The best parameter is determined. In conclusion, the smaller the micro-bubble size, the lower the tensile strength until it reached optimum point. After the optimum point, the smaller the micro-bubble size, the higher the tensile strength will be.

ABSTRAK

Dalam beberapa dekad masa, teknologi kimpalan telahpun ditingkatkan mutunya dan terdapat beberapa teknik kimpalan baru yang telahpun dicipta. Antaranya ialah teknik kimpalan dengan menggunakan laser carbon dioksida (CO_2) yang kini telah memainkan peranan yang amat penting dalam era ini. Dalam projek ini, gabungan terbaik sifat-sifat optima laser CO_2 telah disiasat. Terdapat tiga sifat laser yang telah disiasat dalam projek ini, iaitu: jarak antara bahan kimpalan dengan kanta, kelajuan kimpalan, dan bilangan kimpalan. Kuasa laser telah detetapkan pada 75 Watt. Ketiga-tiga sifat laser ini telah dikategorikan dalam kumpulan dengan menggunakan Kaedah Taguchi dalam perisian Minitab. Kumpulan-kumpulan ini kemudiannya disiasat dari segi “tensile strength” dan “micro-bubble Size”. Satu jadual ANOVA telah disediakan dan “ranking” untuk setiap kumpulan telah ditetapkan. Selepas itu, beberapa Graf akan telah disediakan untuk mencari hubungan antara “tensile strength” dengan “micro-bubble Size”. Gabungan sifat-sifat laser yang terbaik telah dikenalpasti.

Kesimpulannya, semakin besar “micro-bubble Size” semakin tinggi “tensile strength” sehingga titik gabungan terbaik dicapai. Selepas titik gabungan Terbaik, didapati semakin kecil “micro-bubbleSize”, semakin tinggi “ tensile strength”.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

In the last few decades, the technology of welding has been improved and there are several types of welding technology being invented. One of the great inventions is the laser welding. The first laser was invented in the year of 1960 by the Theodore Maiman (Wikipedia, 2012). Laser is a device that emits light (infrared ray) through a process of optical amplification based on the stimulated emission of photon.

There are several types of laser nowadays and they are divided into gas laser type, chemical laser type, dye laser type, Metal-vapor laser type, Solid-state laser type, semiconductor laser type, and etc. The examples of gas laser type are helium-neon laser, Argon Laser, Krypton Laser, Xenon ion Laser, Nitrogen Laser, Carbon Dioxide Laser (CO_2), and Carbon Monoxide Laser. In this research, carbon dioxide Laser will be focused.

CO_2 laser has the wavelength of 10.6µm. It is divided into transverse (high power) and longitudinal (low power) electrical discharge. Recently, CO_2 laser applications are used mainly on cutting, surgery and welding. However, the welding is only limited on metal welding due to its properties of high penetration power. High penetration power delivered high amount of energy to the metal causing the metal to melt. Due to this property, CO_2 laser is not suitable to be used in acrylic welding.

However, in this study, an experiment of acrylic welding by low power Carbon Dioxide laser will be carried out. In the previous study, it was found that the welding of acrylic was done by using other kind of laser, namely – Solid-state laser. The welding is done by overlapping the two materials instead of welding them side by side. Therefore, this research will be done on the joining of acrylic side by side using low power Carbon Dioxide Laser.

1.2 PROBLEM STATEMENTS

i. The use of low power Carbon Dioxide Laser is limited in certain field only and it is hoped that it can be further used especially in the joining of acrylic.
ii. The acrylic joined by using adhesive is not strong and tidy. Thus a research is being carried out on it.

1.3 PROJECT AIM AND OBJECTIVES

i. To study about the optimum parameter that is suitable in the welding of acrylic.
ii. To investigate the mechanical properties as well as optical microstructure of joint.

1.4 PROJECT SCOPES

i. The investigation will be carried out on stand-off distance, welding speed, and number of pass.
ii. The mechanical properties will be investigated using tensile test and the micro-bubble size test.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will explain about the important issues that needed to be considered when a welding is to be performed. Basically, laser acrylic welding has advantages over the traditional technique such as adhesives, hot plate welding, ultrasonic welding, rotation welding, and friction welding (Mladen et al., 2008).

Laser welding is divided into conducting and keyhole mode. Conduction mode welding is done by heat transfer from the laser beam to the surface through thermal convection and from the surface into the material by thermal conduction. As for the keyhole mode welding, it is done by laser beam energy that transfers deep into the material through a cavity.

Laser is a kind of beam which is produced through the focus of light into a small spot and thus produces a high penetration power. Therefore, it has to be controlled in the aspect of the Stand-off Distance, Welding Speed, Number of Pass and etc. By controlling these aspects and parameters, it can be used in variable type of fields.

2.2 TYPE OF LASER WELDING

Laser is divided into several types which are gas laser, chemical laser, dye laser, Metal-vapor laser, Solid-state laser, semiconductor laser. This laser has various type of wavelength and it can be used in different field according to their wavelengths.

The brief categories descriptions of the laser are shown in the Table 1 and Figure 1 below:

Table 1: Categories of Laser (Wikipedia, 2012)

Gas Laser Type	Helium-neon laser, Argon Laser, Krypton Laser, Xenon ion Laser, Nitrogen Laser, Carbon Dioxide Laser, and Carbon Monoxide Laser.
Chemical Laser Type	Hydrogen Fluoride Laser, Deuterium Fluoride Laser, Chemical Oxygen-Iodine Laser(COIL), and All-Gas-Phase Iodine Laser(AGIL)
Dye Laser Type	Dye Lasers
Metal Vapor Laser Type	Helium-Cadmium metal-vapor laser, Helium-Mercury, Helium-Selenium, Helium-Silver, Strontium Vapor Laser, Neon-Copper, Copper Vapor Laser, and Gold Vapor Laser
Solid State Laser Type	Ruby Laser, Nd:YAG Laser, NdCrYAG Laser, Er:YAG Laser, Neodymium YLF Solid-state Laser, Neodymium doped Yttrium orthovanadate Laser, Nd:YCOB Laser, Nd:Glass Laser, Titanuim Sapphire Laser, Thulium YAG Laser, Ytterbium YAG Laser, and etc.
Semiconductor Laser Type	Semiconductor Laser Diode, GaN, AlGalnP, ALGaAs, InGaAsP, Lead Salt, Vertical Cavity Surface Emitting Laser, Quantum Cascade Laser, and Hybrid Silicon Laser

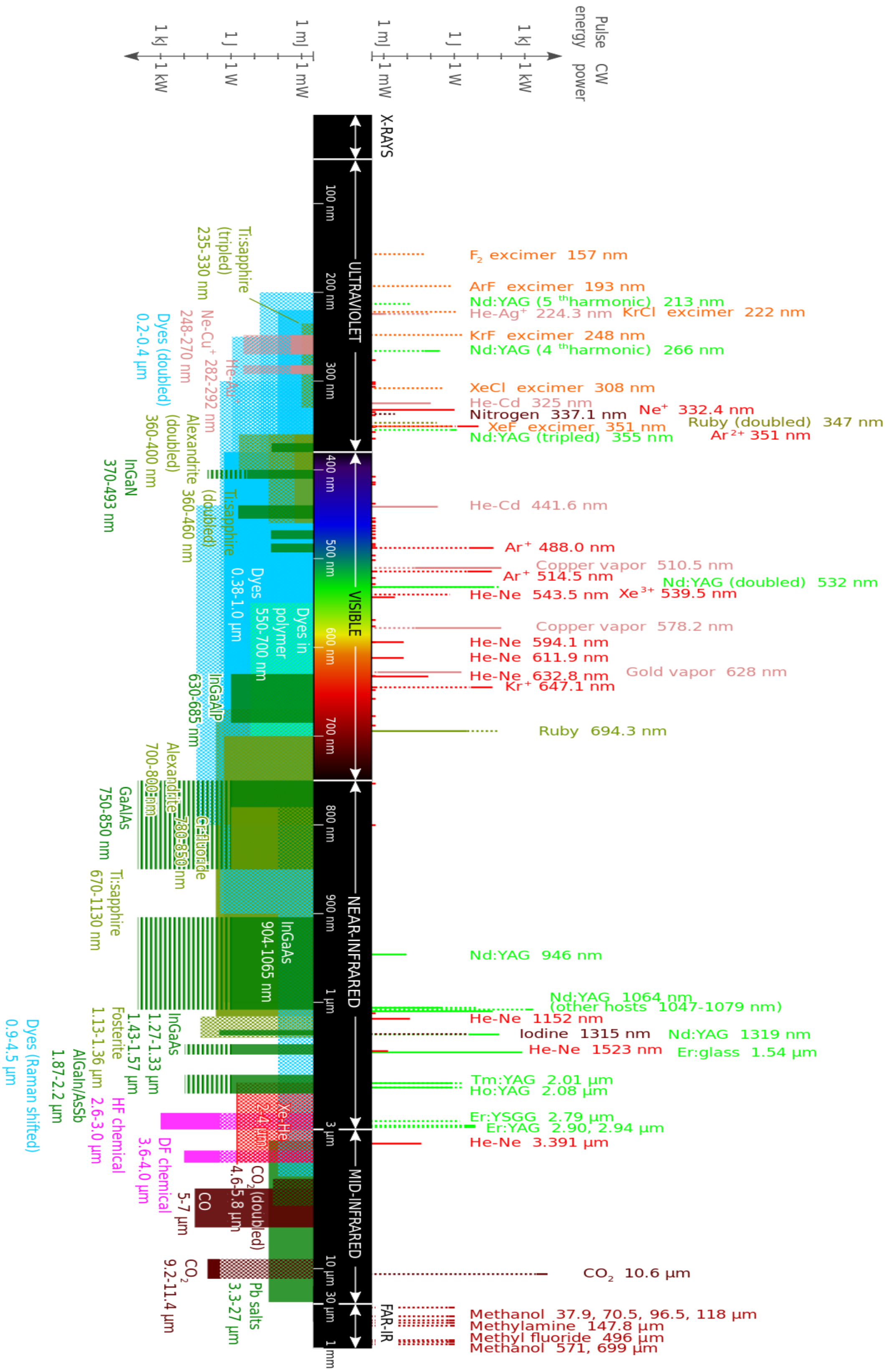

Figure 1: Laser Wavelength (Wikipedia, 2012)

2.3 PARAMETERS OF THE LASER

In laser welding which is similar to laser cutting, it is important to control the parameter of the laser in order to get a high quality weld joint. The parameter can be varied in different aspects such as stand-off distance, welding speed, and number of pass. The combination of these parameters will result in different joint strengths.

In the previous experiment (Mitra et al., 2011), it is found that the parameter of laser welding is approximated as shown in the Table 2 below:

Table 2: Parameter of Welding (Mitra et al., 2011)

Parameters	Units	Notations	Limits				
			-2	-1	0	1	2
Power	**Watt**	**P**	8	11	14	17	20
Welding Speed	**mm/min**	**S**	240	420	600	780	960
Defocal position	**mm**	**F**	25	30	35	40	45

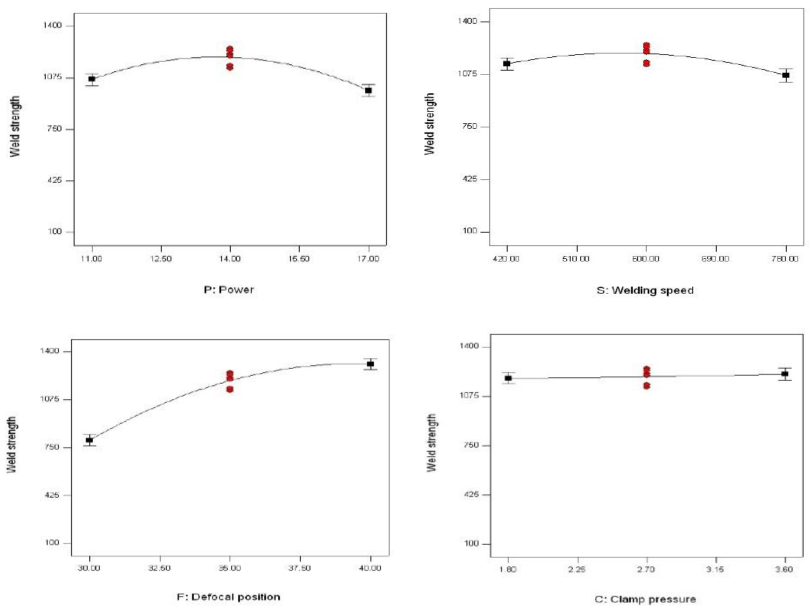

Figure 2: Investigation Result (Mitra et al., 2011)

The research showed that the weld strength of the specimen increased until it reaches 14 Watts while the other parameters remain constant. Further increase the weld power will decrease the weld strength. In this case, 14 Watt will be maximum point.

For the second case, the welding speed was increased from 240mm/min to 960mm/min. The weld strength increased until it reached 600mm/min and then decreased. It is shown that the maximum welding speed is 600mm/min with the other parameters is remains constant.

For the third case, the defocal position was increased from 25mm to 45mm. With the other parameter remain constant, the weld strength keep on increasing. This situation shows that the larger the defocal position, the higher the welding strength. In this case, the defocal position should be further investigated until it reaches its optimum point.

In another experiment (Bappa et al., 2010), the parameter used is very similar. The parameter is as shown in the Table 3 below:

Table 3: Parameter of Welding (Bappa et al., 2010)

Parameters	Unit	Limits				
		-2	-1	0	+1	+2
Power, P	Watt	16.00	19.00	22.00	25.00	28.00
Welding speed, S	mm/min	240.00	300.00	360.00	420.00	480.00
Stand-off distance, F	mm	24.00	28.00	32.00	36.00	40.00
Clamp Pressure, C	MPa	3.30	6.30	9.30	12.30	15.30

Experimental information						Results	
Std. order	*Run order*	*Welding parameters* P (watt)	S (mm/min)	F (mm)	C (MPa)	*Lap-shear strength* (N/mm)	*Weld-seam width* (mm)
1	4	19.00	300.00	28.00	6.30	35.23	2.25
2	16	25.00	300.00	28.00	6.30	36.97	2.58
3	29	19.00	420.00	28.00	6.30	36.17	1.92
4	1	25.00	420.00	28.00	6.30	37.34	2.18
5	13	19.00	300.00	36.00	6.30	43.80	2.89
6	23	25.00	300.00	36.00	6.30	56.15	3.15
7	22	19.00	420.00	36.00	6.30	15.34	2.42
8	24	25.00	420.00	36.00	6.30	28.63	2.43
9	28	19.00	300.00	28.00	12.30	37.86	2.24
10	20	25.00	300.00	28.00	12.30	38.86	2.65
11	11	19.00	420.00	28.00	12.30	41.74	1.96

Figure 3: Investigation Result (Bappa et al., 2010)

Experimental information						Results	
Std. order	*Run order*	*Welding parameters* P (watt)	S (mm/min)	F (mm)	C (MPa)	*Lap-shear strength* (N/mm)	*Weld-seam width* (mm)
12	27	25.00	420.00	28.00	12.30	38.11	2.22
13	21	19.00	300.00	36.00	12.30	46.03	2.88
14	30	25.00	300.00	36.00	12.30	51.00	3.33
15	3	19.00	420.00	36.00	12.30	19.54	2.46
16	15	25.00	420.00	36.00	12.30	24.74	2.46
17	9	16.00	360.00	32.00	9.30	41.54	2.21
18	10	28.00	360.00	32.00	9.30	49.29	2.80
19	14	22.00	240.00	32.00	9.30	46.57	3.04
20	26	22.00	480.00	32.00	9.30	21.23	1.84
21	7	22.00	360.00	24.00	9.30	16.40	2.08
22	6	22.00	360.00	40.00	9.30	14.10	3.23
23	17	22.00	360.00	32.00	3.30	44.83	2.35
24	5	22.00	360.00	32.00	15.30	50.34	2.42
25	19	22.00	360.00	32.00	9.30	45.74	2.59
26	18	22.00	360.00	32.00	9.30	48.11	2.61
27	8	22.00	360.00	32.00	9.30	46.63	2.55
28	12	22.00	360.00	32.00	9.30	46.23	2.43
29	25	22.00	360.00	32.00	9.30	48.69	2.52
30	2	22.00	360.00	32.00	9.30	47.43	2.40

Figure 4: Continue of Investigation Result (Bappa et al., 2010)

2.4 PROPERTIES OF ACRYLICS

Acrylic is a kind of thermoplastic. Understanding the thermoplastic means understand the acrylic. Thermoplastic are polymeric materials with linear macromolecules synthesized by addition or condensation polymerization. Thermoplastic soften upon heating and can be remolded and recycled. Thermoplastic solidify when they cool, restricting the motion of the long molecules and they can be in amorphous or semi crystalline (Mladen et al., 2008). Table 4 and Figure 5 show the properties of the acrylic.

Table 4: Properties of Acrylics (Muzzy J.D et al., 2000)

Type of Acrylic	T_m(℃)	T_g(℃)
ABS	Amorphous	100
PBT	235	-
PC	Amorphous	150
PEEK	335	145
PMMA	Amorphous	100
POM	175	-75
PP	165	-20
PVC	Amorphous	85

Polymer	Acronym	T_g (°C)	T_m (°C)	CTE (10^{-6}°C^{-1})	Water absorption (%)	Solvent resistance	Acid/base resistance	Optical transmissivity	
								Visible	UV[a]
Cyclic olefin (co)polymer	COC/COP	70–155	190–320	60–80	0.01	Excellent	Good	Excellent	Excellent
Polymethylmethacrylate	PMMA	100–122	250–260	70–150	0.3–0.6	Good	Good	Excellent	Good
Polycarbonate	PC	145–148	260–270	60–70	0.12–0.34	Good	Good	Excellent	Poor
Polystyrene	PS	92–100	240–260	10–150	0.02–0.15	Poor	Good	Excellent	Poor
Polypropylene	PP	−20	160	18–185	0.10	Good	Good	Good	Fair
Polyetheretherketone	PEEK	147–158	340–350	47–54	0.1–0.5	Excellent	Good	Poor	Poor
Polyethylene terephthalate	PET	69–78	248–260	48–78	0.1–0.3	Excellent	Excellent	Good	Good
Polyethylene	PE	−30	120–130	180–230	0.01	Excellent	Excellent	Fair	Fair
Polyvinylidene chloride	PVDC	0	76	190	0.10	Good	Good	Good	Poor
Polyvinyl chloride	PVC	80	180–210	50	0.04–0.4	Good	Excellent	Good	Poor
Polysulfone	PSU	170–187	180–190	55–60	0.3–0.4	Fair	Good	Fair	Poor

T_m melting temperature, *CTE* coefficient of thermal expansion

Figure 5: Physical Properties of Thermoplastics (Chia et al., 2009)

2.5 COST CONSIDERATION

In choosing a suitable laser for the acrylic welding, the variable cost of the laser should be considered. For example, the occupied space of the laser, maintenances, electric consumptions fees, availability of the replacements part and etc.

Figure 6 below (Quintino et al., 2010), shows the comparison between various types of laser with various types of expanses over 8 years that needed to be taken into considerations while choosing a laser. Carbon Dioxide laser is one of the lasers that required the lowest cost.

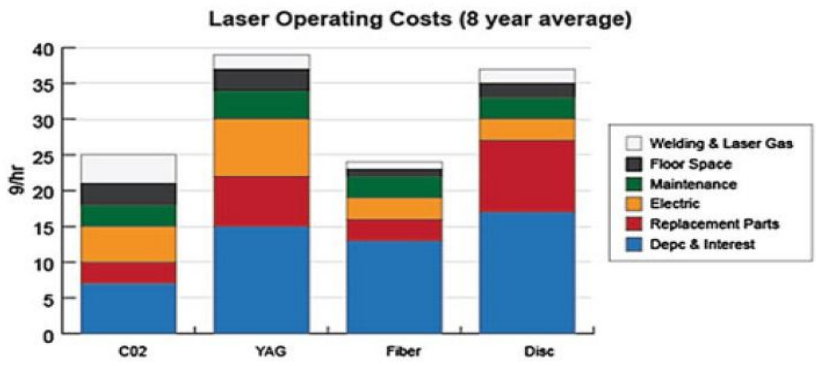

Figure 6: Laser operating cost estimation (Quintino et al., 2010)

2.6 COMPATIBILITY INVESTIGATION

Laser welding is a process in which the heat is transferring of energy to the specimen through the emission of ray. The specimen that is exposed to the ray will absorb the heat from the ray. This will increase the energy of the molecule and induce the rate of vibration of the molecule. At a certain level (melting point), the specimen will start to melt and this induced the welding process to be occurred.

However, not every thermoplastic can be welded together. The main reason is due to the difference of properties especially the melting point. Thermoplastic with high melting point can’t join with thermoplastic with low melting point due to the gap between them. When heat is applied, the thermoplastic with lower melting point will melt first while the other remains in solid state. This will result in an improper joint of the molecules thus reduce the strength of the joint.

Table 5 below is the combination of the thermoplastic that is compatible and has a high quality joint while the Figure 7 below shows the defect of the welding:

Table 5: Compatibility of Thermoplastics (Steen et al., 2012)

Transparent	Absorbing							
	ABS	PBT	PC	PEEK	PMMA	POM	PP	PVC
ABS	Perfect							
PBT		Perfect						
PC	Good		Perfect		Good	Good	Poor	Good
PEEK				Perfect				
PMMA	Good		Good		Perfect	Good	Poor	Good
POM	Poor		Good		Good	Perfect	Poor	Poor
PP	Poor		Poor		Poor	Poor	Perfect	Poor
PVC	Good		Good		Good	Good	Poor	Perfect

Perfect Good Poor

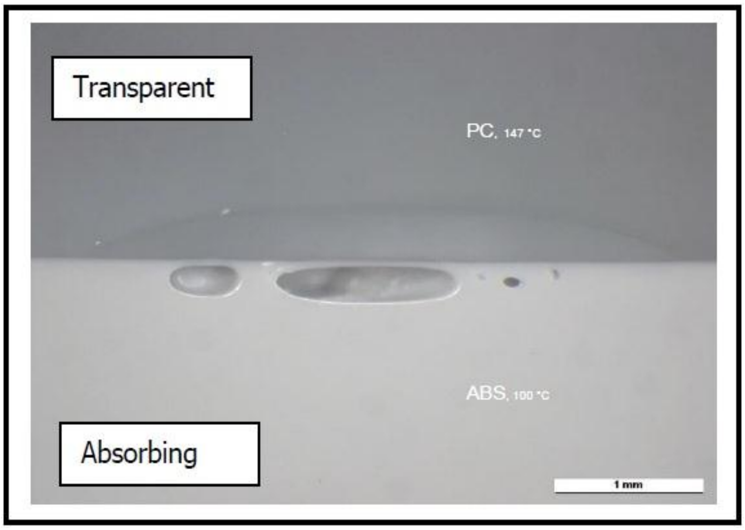

Figure 7: The Effect of incompatible material (Steen et al., 2012)

2.7 ADVANTAGE OF ACRYLIC WELDING BY LASER

In the process of welding, most of the time, the structure of the specimen will be damaged and thus will reduce the strength of the join. The advantage of welding acrylic using laser is that laser only apply heat on the specific area and the heat applied area is small if compare to others type of joining. Because the laser process is non-contact process, the wear and tear associated with conventional method is absent, preventing the product from any damage and deformation (Ario et al., 2011).

The welding of acrylic by laser will minimize the Heat Affected Zone (HAZ) on the structure. Thus, the molecular structure of the specimen will not change a lot and this indicates that the original properties of the specimen are remained. Apart from that, welding of laser also produce a better surface finishing.

2.8 TENSILE TEST

Tensile test is one of the most comment tests for determining the mechanical properties of the material such as strength, ductility, elastic modules, toughness and strain hardening. First of all, the test requires the preparation of the test specimen. The specimen is prepared according to the ASTM specifications of appropriate corresponding organization in other country. The specimen has original gage length l_0 in which generally is 50mm and a cross sectional area A_0 usually with a diameter of 12.5 mm. This specimen is mounted between the jaws of a tensile testing machine. The tensile test machine is equipped with various controls in order to test the specimen at different rates of deformation and temperature at the same time. (Kalpakjian and Schmid et al., 2001)

It is important to know whether the material is strong enough and rigid enough to withstand the loads as the material is used in the engineering structure that will be subjected to load.