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Determination of Ultrasonic Welding Optimal Parameters for Thermoplastic Material of Manufacturing Products

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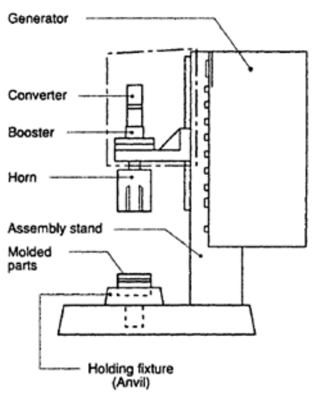


Abstract

Ultrasonic welding had been widely used in various manufacturing industries such as aviation, medical, electronic device and many more. It offers a continued safe operation, faster and also low cost as it able to join weld part less than one second and also simple to maintain the tooling devices. Though ultrasonic welding brings a lot of advantages in assembly especially in thermoplastic material of manufacturing product, it also has a dominant problem to be deal with. The problem in ultrasonic welding is poor weld quality due to improper selection of ultrasonic welding parameters especially in near field configuration. Thus, an optimal combination of parameters is crucial in order to produce good quality weld assembly for this configuration. In this paper, ultrasonic welding process, ultrasonic weld joint defects and determination of optimal parameters for thermoplastic material had been discussed thoroughly.

Keywords: Ultrasonic welding; thermoplastic; near field configuration; optimal parameters

Abstrak

Kimpalan ultrasonik telah digunakan secara meluas dalam pelbagai industri pembuatan seperti penerbangan, perubatan, alat elektronik dan banyak lagi. Ia menawarkan operasi yang selamat, cepat dan juga berkos rendah kerana ia pemasangan kimpalan boleh dilakukan kurang daripada satu saat dan alat peralatannya adalah mudah untuk diselenggarakan. Walaupun kimpalan ultrasonik membawa banyak kelebihan dalam penyambungan terutama dalam pembuatan bahan termoplastik, ia juga mempunyai masalah yang dominan yang perlu dihadapi. Masalah dalam kimpalan ultrasonik adalah kualiti kimpalan yang rendah disebabkan pemilihan parameter kimpalan ultrasonik yang tidak wajar terutama dalam konfigurasi bidang terdekat. Oleh itu, gabungan optimum parameter adalah penting untuk menghasilkan kualiti yang baik bagi pemasangan kimpalan untuk konfigurasi ini. Dalam kertas ini, proses kimpalan ultrasonik, kimpalan ultrasonik kecacatan sendi dan penentuan parameter optimum untuk bahan termoplastik telah dibincangkan dengan teliti.

Kata kunci: Ultrasonik kimpalan; komposit termoplastik; sejarah semula jadi; usaha penerokaan

1.0 INTRODUCTION

Michael J. Troughton [1] describes ultrasonic welding as one of the common used welding methods for joining thermoplastics where it uses high frequency current; typically between 20–40 kHz which are beyond the range of acceptance human hearing. This frequency is used to produce low amplitude (1–25 µm) mechanical vibrations where the vibrations generate heat at the joint interface of the parts being welded, consequently melt the thermoplastic materials and finally weld formation after cooling. Ultrasonic welding is the fastest known welding technique where it ables to weld less than one second. Figure 1 shows an ultrasonic welding machine with its welding sample. As can be seen in Figure 1, ultrasonic welding consists of power supply, converter or transducer, booster and a horn or sonotrode. The detail process of ultrasonic welding will be further explained in the next section of this paper.

The applications of ultrasonic welding are extensive and can be found in many manufacturing industries such as electrical and computer, automotive and aerospace, medical, and packaging. Though ultrasonic welding can be seen and applied in various manufacturing industries, ultrasonic welding is not applicable for thick parts specimen since its difficult to melt the material between the joint interface. It is only suitable and applicable for wires, microcircuit connections, sheet metal, foils, ribbons and meshes which are thin and easier to melt.

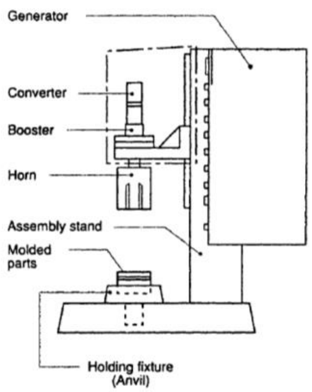


Figure 1 Schematic of ultrasonic welding machine

Weldability of parts being welded is always affected by the properties of the material. Anixter in [3] exemplifies that thermoplastic is easier to be weld using ultrasonic welding if compared to thermoset as thermoplastic has the ability to be melted and take on a new shape as it cool plus it can be done over and over again. But it is different to thermoset material where it will take its final shape and cannot be recycled or reused. If take a look deeper into thermoplastic material types, amorphous thermoplastic is simpler to be welded rather than semicrystalline thermoplastics because material with higher melting temperature requires more energy for ultrasonic welding and resin with lower modulus of elasticity transmits energy to the join energy much lesser than the stiffer raisin.

The major problem that occurs in most ultrasonic welding process is the improper selection of setting parameters. This improper selection of parameters will cause bad weld quality and strength of the weld. It is hard to find suitable welding parameters because it have a lot of combination of parameters and it is very costly to do all the experiment using traditional methods to find the best parameters for the weld part. Thus, it is very important to find the best combination of parameters that will produce maximum weld strength. There are five main parameters that need to be considered with in producing good quality ultrasonic welding which are weld pressure, weld time, hold time, down speed and amplitude. Before we determine the optimal parameters, ultrasonic welding process, material characteristics and welding joint design need to be fully comprehends.

■2.0 METHODOLOGY

2.1 Welding Process

In general, based on its component itself as in Figure 1, welding process starts from the power supply where it converts low voltage electricity to high frequency electrical energy and next the converter or transducer converts electrical energy to mechanical vibratory energy. Subsequently, the booster adjusts the amplitude of the vibrations and transmits them to the horn where it transmits vibratory energy to the parts. Sample was hold in place and pressure was applied during the welding and thus joints the parts.

In other way of illustration, ultrasonic welding process starts by clamping the workpiece between the horn and anvil. Then, the horn vibrates and starts to produce heat which will automatically melt the contact surface consequently build up deformation layer. Finally weld area was performed and joined the workpiece together. This ultrasonic welding process can be seen much clearer in Figure 2. [4]

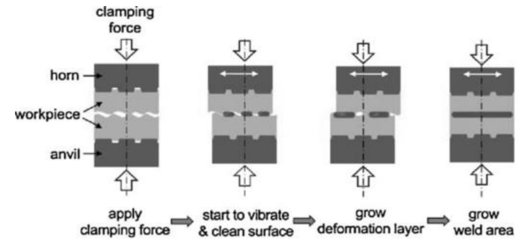


Figure 2 Schematic of ultrasonic welding process [4]

2.2 Characteristic of Material Selection

In this paper thermoplastic composite material had been chosen and focused for ultrasonic welding process since its becoming greater interest in industry as a result of their growing potential for high performance application in manufacturing industries. Moreover, thermoplastic composites have high strain to failure, increased fracture toughness, better impact tolerance, and short processing cycle time, infinite help life of prepreg, recyclability and reparability are few of reasons of most cited and prove of their growing popularity [5]. Benatar in [6] strengthen the point where thermoplastic composites have many potential advantages especially when it compared to thermosetting based composites where it have better solvent resistance, greater damage tolerance and most importantly is the potential for lowering manufacturing costs. Offringe [9] proven that the cost effective processing is the main reasons in the application of thermoplastics.

Table 1 Thermoplastic characteristics [3]

Characteristics	Thermoplastics
High temperature mechanical performance	Poor to good
Coefficient of friction	Very low to moderate
Elongation	Poor to good
Tensile Strength	Poor to excellent
Colorability	Good to excellent
Heat deformation	Poor to good
Cold temperature compatibility	Poor to excellent

Furthermore, thermoplastic composites can generally be heated, deformed to complex shapes and then cooled to solidify the matrix. Apart from that, thermoplastic composites are normally required higher forming temperatures and pressures than the thermosetting systems. Hence, thermoplastics composites may not enjoy as a high level of integration as it is currently obtained with the thermosetting systems. As a consequence of this, the joining of thermoplastic composites is becoming cost effective, so rapid and reliable joining methods must be developed where ultrasonic welding can be helpful in joining the thermoplastic composites. Table 1 shows some characteristics of thermoplastic that should be consider in choosing material in any applications.

2.3 Ultrasonic Welding Joint Design

Basically, there are two types of joint design which are energy director joint and shear joint. But, in this research, energy director joint had been selected as shown in Figure 3. According to Michael in [10], joint design is the most important thing in producing good ultrasonic welding joints where it relies on the type of thermoplastic to be bonded, part geometry and requirement of the weld.

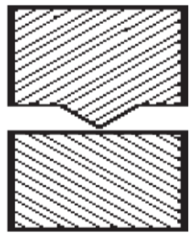


Figure 3 Schematic of energy director joint [11]

An energy director is normally a triangular edge on one of the joint surfaces. It serves to concentrate ultrasonic energy and rapidly initiates melting of the joining surfaces. Common joints which usually used an energy director joint design are butt joints, step joint and tongue and groove joints. This type of joint is commonly used for amorphous plastics [12] since its flow and solidifies progressively.

2.4 Ultrasonic Welding Configurations

Other than joint design, ultrasonic welding configurations also play an important role in order to produce good quality welding. There are two types of configurations which are near field configurations (< 6 mm) and far field configurations (>6 mm), but in this research near field configurations had been chosen as shown in Figure 4 which is the distance of the horn from the joint area is less than 6 mm.

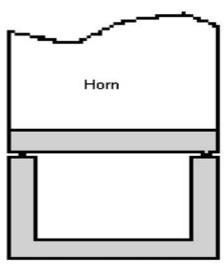


Figure 4 Near field configurations schematic [11]

2.5 Characteristic of Material Selection

Designing of jig and fixtures is also a crucial process in promising a good quality welding as it make sure that the part to be weld could be hold perfectly while welding process is done. Jig and fixtures need to be design by following the part model to be weld so that it will not vibrated and moved while welding.

2.6 Parameter Setting

There are five main parameters of variables in that have been considered in this paper which is weld pressure, weld time, hold time, down speed and amplitude. These parameter need to be control carefully and an optimized parameter should be acquired so that a good weld quality can be achieved. It is important to select optimum combination parameters because improper selection will lead to bad quality welding.

(1) *Weld pressure, Pw:* the pressure that exerted on the parts being joined.
(2) *Weld time. Tw:* length of time for the ultrasound being applied to the part to be weld.
(3) *Hold time, Th:* delay time after the ultrasonic turned off before the clamping force was released.
(4) *Down speed, Sd:* the length of time for the horn to travel the weld distance.
(5) *Amplitude, A:* the displacement anti node need to be at the horn interface so that the dynamic stress can be in the plane of contact between the two parts being welded.

2.7 Destructive Testing for Quality Inspection

Pull/Push test process had been used to test the strength of ultrasonic welding joint. This test is used to ensure the lens is fully bonding to the front housing after the ultrasonic welding process. This test was done for five pieces from the starting, right after the parameters had been set up and one piece for every one hour during the welding process. Figure 5 shows the schematic of how pull/push test operates. For this research, the pull/ push test specification must be exceed 5Kgf to guarantee that the joint is sufficient.

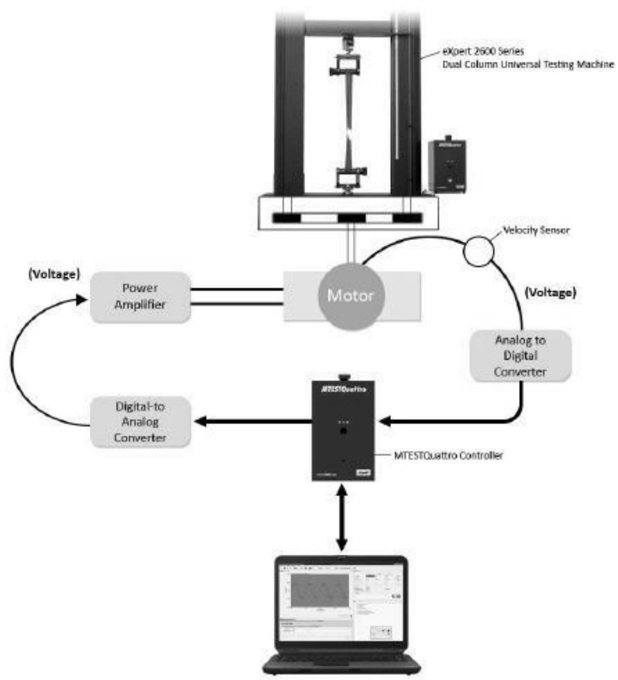


Figure 5 Schematic of pull/push test operation

2.8 Non Destructive Testing for Quality Inspection

Another method to ensure the quality of the ultrasonic welding is by using the ultrasonic testing. This method is one of Non Destructive Testing method where it ensures continued safe operation without added any defects to the specimen itself. Figure 6 shows the fundamental technique of defect detection using ultrasonic testing.

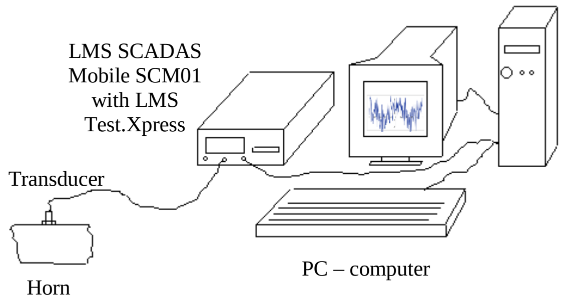


Figure 6 Ultrasonic testing technique

This technique works as sound produced by the vibrating body of ultrasonic welding machine and its travel in the form of wave. This wave or signal is detected using the transducer which capable to transmit and receiving the sound energy. A piezoelectric element in the transducer converts electrical energy into mechanical vibration (sound), and vice versa. This transducer is applied towards the horn of the ultrasonic welding machine and transmits the waveform towards the LMS SCADAS Mobile SCM01 and with the aid of LMS Test.Xpress, the waveform is plotted into a significant graph showing the amount of reflected sound energy versus time which provides the inspector information about the size and location of features that reflect the sound

■3.0 RESULTS AND ANALYSIS

3.1 Difficulty in Welding and Defects Occurrence

The most difficult thing in welding is before the welding process is done which is to set up the optimal parameters. Different parameters will be used for different models. The parameters value was selected based on its material, area to be weld, thickness, shape and many more. During welding process, the difficulties in welding may due to the unbalanced work base (table that used to support the ultrasonic welding machine) where the structure of the work base is not strong enough to support the ultrasonic welding machine. This might constructs the whole parts vibrated during the welding process and causing defect to the weld area part.

In addition, defect may also occur from the operator handling. Operator is not efficient enough during the welding process. They may become tired and stiff while handling the machine and unconsciously makes a mistake that brings to defect and waste. The example of defect that occurred during welding process is horn mark and dented defects. Defect is not only occurring during the welding process, it may also occur after the welding process which is due to the handling and packaging. Usually, type of defects that occurred during this interval time is scratch and dented. Figure 8 shows the example of defects in ultrasonic welding.

3.2 Optimal Parameters after Determination

Optimal parameters with combination of weld pressure, weld time, hold time, down speed and amplitude were shown in Table 2. This result were compared with the optimal parameters that obtained by using Taguchi method.

Table 2 Determination of optimal parameters

Parameters	Optimal Parameters	
	Try and Error Method	***Taguchi Method***
Weld Pressure,Pw (bar)	2.0	2.1
Weld Time,Tw (s)	0.3	0.1
Hold Time, Th (s)	1.0	0.8
Down Speed, Sd (s)	6	8
Amplitude,A (%)	70	90

Taguchi method was used to improve the quality of products and processes. It used simple logic which is sufficient to establish all possible combinations of factors along with allowable ranges of each of the factors involved. Taguchi constructed a special set of general designs for factorial experiments that cover lot applications. This special set of design consists of orthogonal arrays (OA) which helps to determine the least number of experimental needed for a given set of experiment. [13,14] Figure 7 below shows the average values of strength at various levels using Taguchi method.

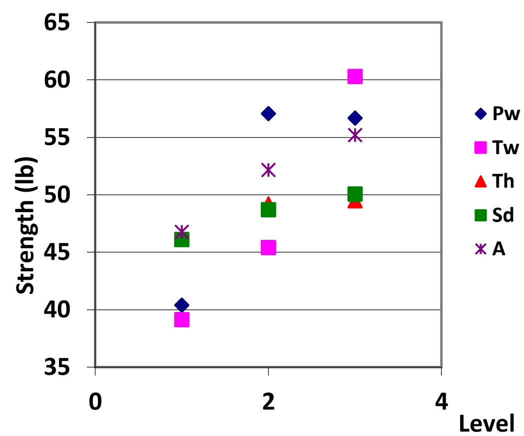


Figure 7 Average values of strength at different levels

From the graph, it can be seen that strength increasing with increasing level of parameters values. But, up to certain point some of the parameters such as weld pressure, and down speed show no significant effect to the weld strength between the second and third level. Whereas weld time seems longer time is needed for the weld to take place, the higher strength of weld it will produce. However, too long weld time may bring to bad quality welding and lead to defects formation. This is same goes to the other parameters. Therefore, it is essential to determine optimal parameters before the ultrasonic welding process.

3.3 Destructive and Non Destructive Testing for Quality Inspection

For the destructive testing method, after using the pull/push test method, it seems that the value is exceeding 5Kgf which is considered fulfilling the specification requirement.

While for non destructive testing which is using ultrasonic testing, the result of the signal graph showing the speed versus time. The important features of this graph that need to be considered with in order to validate the parameters used are optimal are highlighted in Figure 8 below and Figure 9 shows three times of testing that had been done towards the conservative specimen samples.

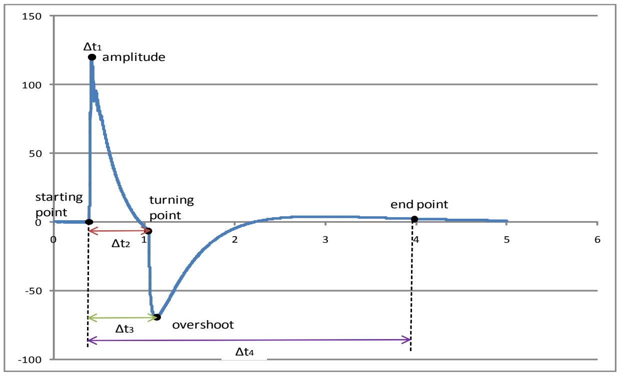
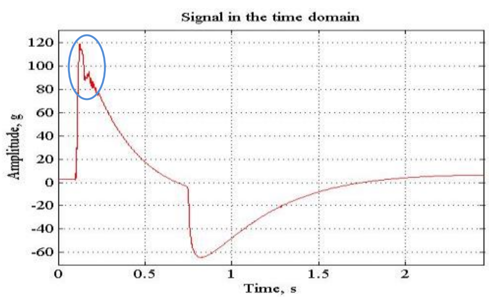
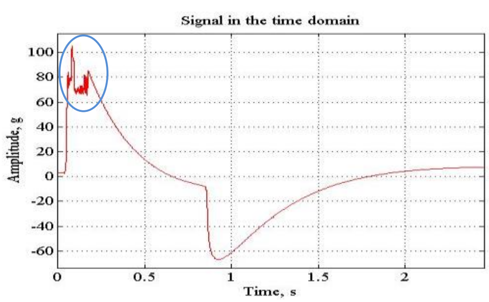


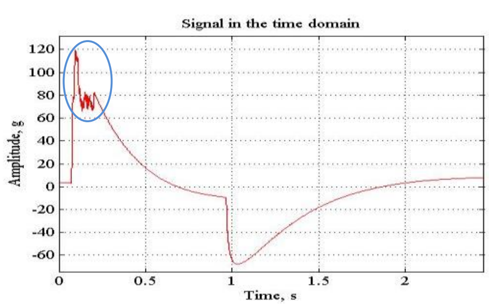
Figure 8 Speed vs. time graph features point



(a) Sample 1



(b) Sample 2



(c) Sample 3

Figure 9 Speed vs. time graph

From Figure 9, we collect some important features points as been point up in Figure 8 to be analyzed and those data can be seen clearly in Table 3.

Table 3 Important features

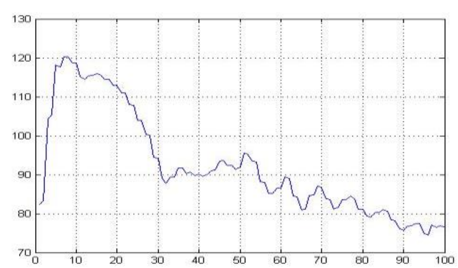
Time Durations	Time (s) Sample 1	Sample 2	Sample 3
Δt_1	0.020	0.135	0.137
Δt_2	0.659	0.965	0.819
Δt_3	0.733	1.033	0.889
Δt_4	3.788	4.268	4.043

Then, we calculate the data to get the minimum, average and maximum of each value of time and result of this calculation is shown in Table 4.

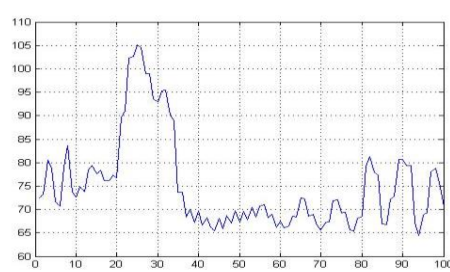
Table 4 Data analysis

Time Durations	Δt_1	Δt_2	Δt_3	Δt_4
Min.	0.020	0.609	0.690	3.788
Max.	0.137	0.965	1.033	4.043
Average	**0.097**	**0.814**	**0.855**	**4.033**

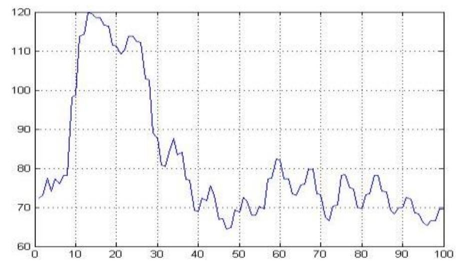
From both Table 3 and Table 4, Δt_1 is time of the starting point where it reach the peak, Δt_2 is the duration time of holding time, Δt_3 is the time where it pressed the specimens to be joint and Δt_4 is the total welding time. From table 3, it can be seen that sample 2 shows the longest time required for Δt_2, Δt_3 and Δt_4 and the shortest time for Δt_1 which is time taken to start and reach its peak if compared to sample 1 and sample 3. While sample 1 shows vice versa with the shortest time in Δt_2, Δt_3 and Δt_4 and the longest time for Δt_1. Therefore we can make an early prediction and said that sample 1 is the best welding and sample 2 is the worst welding. To reinforce this statement we plot another graph which focused on the critical area (blue circle area in Figure 9) of the welding process as can be seen in Figure 10.



(a) Sample 1



(b) Sample 2



(c) Sample 3

Figure 10 Focused signal graph

From graphs in Figure 10, we overlapped sample 1, 2 and 3 in one graphs to make it clearer as in Figure 11. Here, we can seen sample 1 is the fastest to reach the peak and descend uniformly and sample 3 shows not much different to sample 1. While sample 2 is away lower and a little late to reach its peak descend drastically. As we highlighted in dotted line in box, all three signals share some values of 29 where interpolation existence. Thus, in signal analysis it also shows that sample 1 gives the best result and sample 2 is the worst.

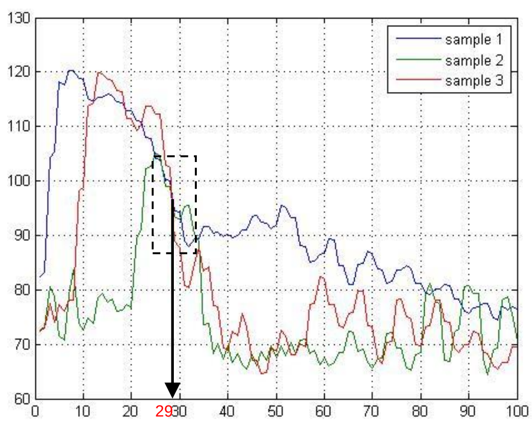


Figure 11 Overlapped signal graphs

■4.0 CONCLUSIONS

Determination of optimal parameters of ultrasonic welding for thermoplastic materials for manufacturing products had been successfully established by using try and error method and also Taguchi method. It can be seen that from these both methods, Taguchi method perform better result compare to the try an error method since it is more sufficient in terms of its low cost and faster. The optimal parameters were selected based on its material characteristic, ultrasonic welding design and its thickness and also welding configurations.

These parameters had been tested by using different approaches which is pull/push testing for destructive testing approach and ultrasonic testing for non destructive testing approach to make sure the quality of the welding. For destructive testing which is using the pull/push test, it seems that the value is exceeding 5Kgf and this is certainly fulfilling the client specification requirement.

Whereas for non destructive using ultrasonic testing shows no defect to the specimen itself after the welding process and the data gathered from the signal detection of ultrasonic testing shows considerable values where it is upon the range of the customer specifications. Though in the welding shows no defects to the specimens for all three samples. Data analysis and signal analysis verified that sample 1 is the best quality sample of welding while sample 3 is the worst welding

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