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Monitoring and Evaluating the Quality of Nugget Nucleation During Resistance Spot Welding Process by Acoustic Emission Method

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ABSTRACT

There are thousands of spot welds on an automobile body; the quality of spot welds determines the safety and performance. The factors of quality for spot weld mainly include the nugget dimension. The strength of spot weld largely depends on the nugget dimension. The physical phases of nugget nucleation in resistance spot welding process can be characterized by the characteristic parameters of AE signals detected.

The aim of the present work is to develop an efficient procedure for processing the informative parameters of AE signals formed in the course of RSW and synthesize a criterion of the quality of spot-welded joints.

Keywords
Acoustic Emission; nugget nucleation; resistance spot welding; defects

1. Introduction and the problem

Joining technology is an integral part of modern manufacturing and joining properties are an important aspect of product properties in general. The increased complexity of vehicle products has also resulted in challenges for joining technologies.
In resistance stop welding , process planning is mainly focused on optimization of process parameters with regard to product properties, process time efficiency and cost of the process.
In the transportation industry, and the automotive industry in particular, resistance spot welding (RSW) has for decades been the main joining technology. The method's low cost, high reliability, high time efficiency, high accessibility and high ability for robot automatization, compared to other joining methods, make it ideal for automotive production.
There are thousands of spot welds on an automobile body, The quality of spot welds determines the safety and performance. The factors of quality for spot weld mainly include the nugget dimension and weld strength. The strength of spot weld largely depends on the nugget dimension (the lateral size of the solidified joint zone) .
By understanding the effect of process parameters and their optimization, the RSW process' result properties and robustness can be improved.
The lack of accurate large scale non-destructive test (NDT) methods for RSW increases the importance of process for RSW applications Therefore, the predictive capability of process tools must be sufficient in order to accurately model production scale RSW processes.

The physical phases of nugget nucleation in resistance spot welding process can be characterized by the characteristic parameters of AE signals detected.
Acoustic emission is an outlet parameter which provides information about the process of resistance spot welding, as well as about the quality of the weld spot. The information gained from acoustic emission can strongly support or reject conclusions about weld quality by simply monitoring a single physical property.
The essential goal of analysing acoustic emission signals is the appropriate determination of acoustic emission sources and the relevant with parameters of welding

In Toyota company they are an employee for testing the nugget of spot welding by hammer and he destroyed a door of the car every 30 door, but by using AE test during the welding process usually test about 2000-3000 spot welding for all car (car by car) , AE feedback control automatically adjusts the required process variables of RSW .

The aim of the present work is to develop an efficient procedure for processing the informative parameters of AE signals formed in the course of RSW and synthesize a criterion of the quality of spot-welded joints. The monitoring and improving the quality of spot welds are an ongoing process in RSW research.

2. Resistance spot Welding

2.1.Resistance spot welding letreture review

2.1.1. Principle of Resistance Welding

The principle of resistance welding is based on Joule heating. The workpieces are clamped between the electrodes by applying an electrode force, then an electric current passes through the top and bottom electrodes and heats the workpieces by Joule heating.

When the temperature at the interface reaches the melting point of the material, a molten nugget begins to form and grow. When the welding current is switched off, this nugget will solidify to form a weld that joins the workpieces together [1]. The generated heat is expressed as the following equation according to Joule's law:

$$Q(t) = \int_0^T R(t).I^2(t).dt \qquad (1.1)$$

$Q = heat\ developed$

$R = ohmic\ resistance$ [Ω]

$I = welding\ current$ $[A]$

$t = time$ [s]

$T = total\ weld\ time$ [s]

there are seven different ohmic resistances in resistance spot welding, as shown in Fig 1.1 , which are:

R1, *R7*: resistances of electrodes.

R2, *R6*: electrode-workpiece contact resistance,

R4, *R6* : workpiece-workpiece faying surface contact resistance

R3, *R5* : base material resistance of workpieces

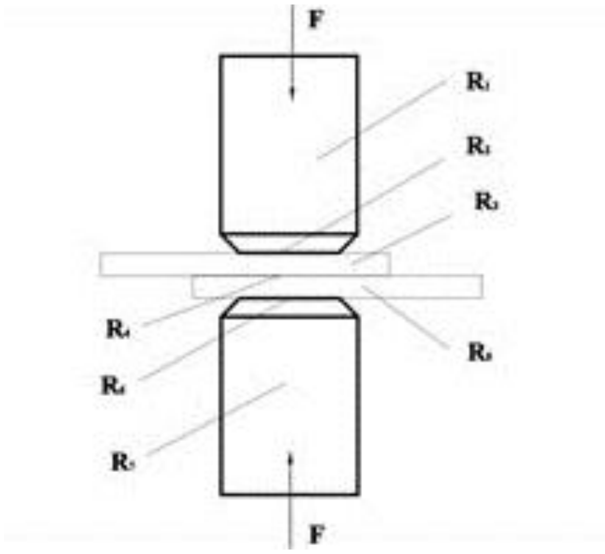


Fig. 1.1. ohmic resistances in resistance spot welding [12]

The resistance distribution and corresponding heat distribution are shown in Fig 1.2.

One way of minimizing the heat development in and around the electrodes is to use copper alloys for the electrodes, because copper alloy has good electrical and thermal conductivities. Another way is by using water-cooling inside the electrodes [2].

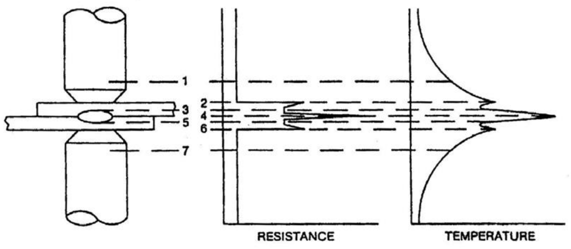


Fig. 1.2. Resistance and heat distributions in resistance spot welding [2]

2.1.2. Process of Resistance Welding

Squeeze time: The electrodes come together and the parts to be joined are compressed between the electrodes, the compression force is built up to a specified amount before the current is passed through.

Weld time: In this period, the weld current is applied, the metals are being heated enough to melt and fuse together to form what is called a weld nugget.

The force is continuously applied and the deformation of workpieces continues.

Hold time: The weld current is ceased but the electrode force is still applied. During this period, the weld nugget cools and the metals are forged under the force of the electrodes. The continuing electrode force helps to keep the weld intact until it solidifies, cools, and weld nugget reaches its adequate strength before the electrode force is finally released [3].

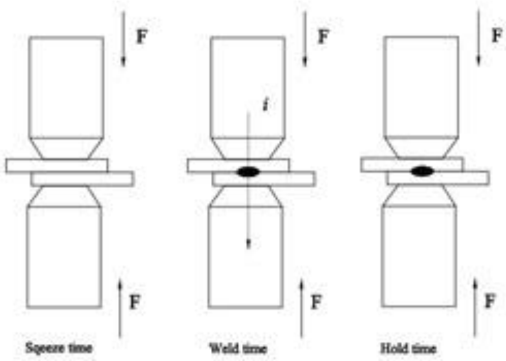


Fig. 1.3. Process of resistance spot welding [3]

2.1.3. Weld Properties and Quality Factors

The main factors affecting the strength of the weld are:

1. Nugget geometry.
2. Indentation.
3. Defects (e.g. voids, cracks and inclusions.)
4. Material phases in the heat affected zone (HAZ).

Fig. 1.4 shows a schematic representation of a spot weld between two plates as well as the geometric factors that affect quality. where the dimensions and features depicted in Fig. 1.4 are visible. For this work, quality inspection focuses on nugget geometry, indentation and defects only [4].

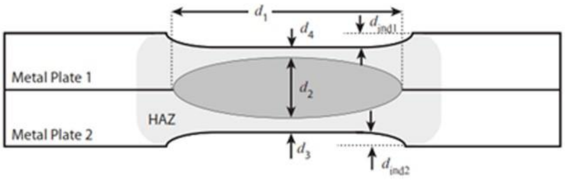


Fig. 1.4. schematic representation of a spot weld between two plates[4]

Schematic of a spot weld cross-section with nugget diameter d, nugget thickness d_2, nugget penetration depth d_3 and d_4 and indentation depths d and d $_{ind2}$. The heat a_ected zone is shown in light gray.

2.1.4. Adjustable resistance welding parameters

The most important adjustable resistance welding parameters are welding current, weld time, electrode pressing force and electrode geometry, and the choice of electrode materials.
The other adjustable parameters include the duration of squeeze and hold time, possible heat treatments before or after welding, adjustment of the up and downslope of the welding current (slope function), changes in electrode force and timing on the basis of work stage, and pulsation of welding current [6].

2.2.Evaluat the quality of the nugget nucleation of resistance spot welding

2.2.1. Breaking and Measuring

Testing and quality management of spot welds It is difficult to visually inspect the size and mechanical properties of spot welds. The easiest way to inspect size is to break the joint and measure the diameter of the weld [6].

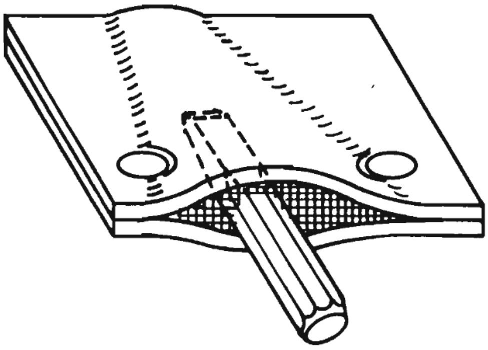


Fig. 2.1. hammer and chisel

2.2.2. Peel test

A simple and much used destructive testing method is the peel test, Figure 2.2, where consecutive welds are made to two metal sheet slit strips, after which the sheets are torn apart. The weld diameter is measured as described above. The peel test can be used to define the weldability range and ideal welding parameters of a material. The peel test is easy to carry out in a production environment and no specific machinery is needed. The test must, however, be complemented with destructive tests of the end products in order to take the workpiece geometry and size into account in the welding process. Brittleness and mechanical properties of the weld can also be deduced from the fracture surface of the opened welds [6].

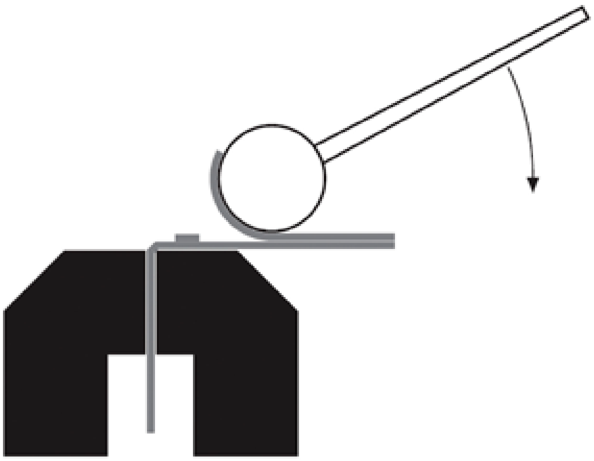


Fig. 2.2. Peel test

2.2.3. Tensile testing

Simple destructive tests can also be complemented with tensile tests to assess the tensile strength of the welds. Specific specimens made of sheets are used in tensile testing. Tensile test require specific machinery[7].

Fig 2.3: Failure of spot welded coupon for pure tensile loading condition [7]

The quality of a weld is ultimately determined by its yield strength.The welded plates of the workpiece are pulled either axially (pull stress) or laterally (shear stress) and the force required to break the weld is measured, however, this destructive form of evaluation is not suitable for inprocess testing of large volumes.

2.2.4. Metallurgical microscope

Welds can also be inspected using a microscope if a microsection of the weld is made. A metallurgical microscope with a magnifying capacity of 10–100 is sufficient for testing, but specific equipment is needed for the making of the microsection. A microscope can be used to inspect the weld for gas pores, cavities, larger fractures and inclusions.

For weld cross section analysis, an AXIOVERT optical microscope (OM) with an inverted light is used to take images of the mounted coupons at 5_ magnification. The welding equipment [7].

2.3. Real time monitoring weld quality of small scale resistance spot welding for titanium alloy [8]

2.3.1. Introduction

Stiffened thin plate structure which is mostly applied to the car body structures consists of frame and sheet. It is a low cost method to reach a high-performance vehicle structure because of requirement low volume materials. Frame is thicker than sheet, so it acts as the reinforcement of this structure. The resistance spot welding (RSW) is generally used to join it.

2.3.2. The gool

failure modes of resistance spot welded thin plate structure, pullout and interfacial failure modes, were investigated based on thickness of joined plates and load secondary voltage to determine the critical nugget diameter.

2.3.3. Material and method

Three pairs of mild steel SS400 plates were joined in a lap joint by resistance spot welding.
The stiffened thin plate structure is that it has differenet thickness of joint sheet materials
Macrostructure observations were carried out using a stereo zoom microscopy
Shear Load Bearing Capacity Tests using tensile – shear sample .
The base metal were measured using microvickers methode on the metallographic specimens with a load of 500 g.

2.3.4. Result

The microhardness of weld nugget was found to be higher than that of HAZ and raw material
welding voltage and holding time make nugget area increase. increasing welding voltage led to increasing nugget diameter.

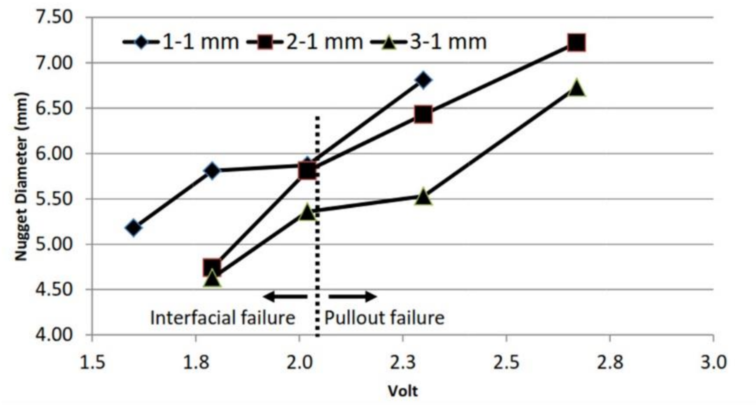


Fig 2.5 . Effect of voltage on the nugget diameter

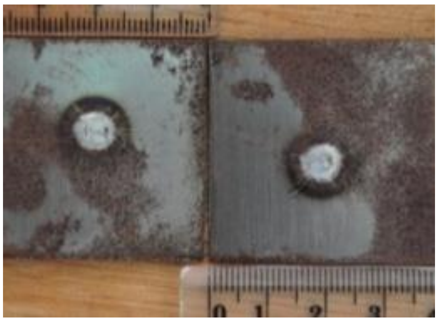
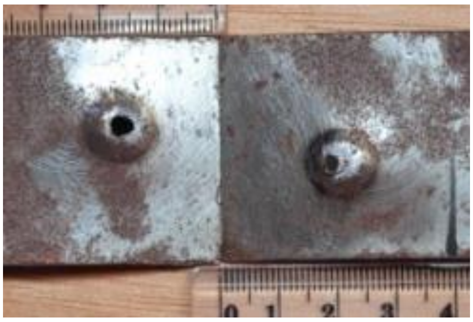


Fig. 2.6 Interfacial failure (IF) mode



pullout failure (PF) mode

Spot weld joints which had smaller nugget diameter than the critical nugget diameter would fail in IF mode whereas the other would fail in PF mode.

2.3.5. Conclusion
Increasing welding voltage made the shear load bearing capacity of RSW joint increase.
In the pullout failure, the bearing capacity increased if the thickness of joined materials increased.

2.3.6. Gaps
But if there no defect , void, flaw

2.4. Welding parameters influence on fatigue life and microstructure in resistance spot welding of 6061-T6 aluminum alloy [9]

2.4.1. Introduction
The need for lightweight alloys and quality welds becomes a great interest in these industries for achieving improved fuel economy for ground vehicles. The resistance spot welding process bonds contacting metal surfaces via the heat obtained from resistance to an electrical current flow. Spot welding provides accelerated speed and adaptability for automation in high-volume and/or high-rate production.

2.4.2. The gool
These tests were used to characterize the fatigue behavior in spot welded specimens to elucidate the influence of the process parameters of welding .
Welded specimens of various nugget sizes were produced in order to realize the correlation between the process parameters and the weld quality

2.4.3. Material and method
The materials used in experiment are The wrought aluminum 6061-T6 alloy. exhibits high yield strength and good ductility properties
By the resistance spot welding machine the two specimens are welded overlay,
welding conditions (‘‘nominal’’, ‘‘low’’ and ‘‘high’’)
Optical microscopy : Specimens were prepared for optical microscopy (OM) analysis of welds of the single-lap joint After cutting.
periodic peel tests were performed on specimens to check the quality of the welds to adjust the parmetrat of the spot weld .
Servo-hydraulic load frame (MTS 810 Material Test System) with the RSW coupon placed in the grips
Fatigue tests and scanning electron microscopy (SEM): After complete failure, post-process scanning electron microscope analysis was performed for different fracture surfaces

2.4.4. Result
- specimens were cross-sectioned and etched. shows Significant pitting and cracks inside of the fusion zone were observed (a). this weld is not acceptable. The nugget is slightly shifted to the top of the joint. This weld is acceptable from shape, dimensions and microstructural points of view (b).

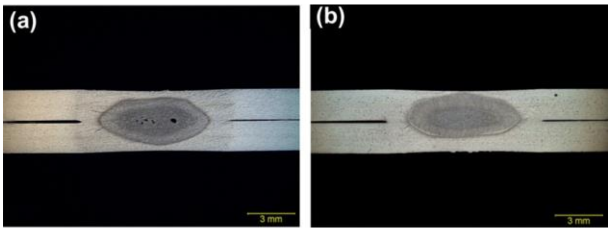


Fig. 2.7. microsection of the weld

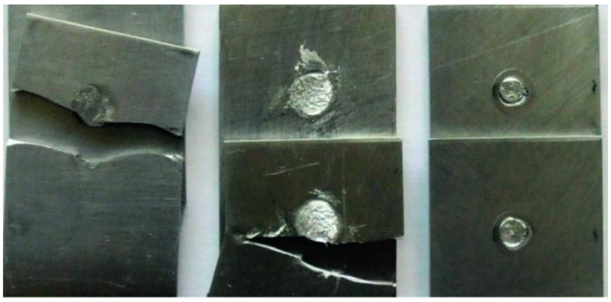


Fig. 2.8. Fractured fatigue resistance spot welding specimens.

- Welding spatter is one of the reasons of starting of fatigue cracks.

2.4.5. Conclusion

Fatigue S–N curves is novel for this research field and was used to characterize mechanical behavior for a 6061-T6 aluminum alloy welding joint at coupon level.
The welding current had a large influence on welding nugget dimensions and lap joint mechanical behavior.
No fatigue initiation sites were observed in the porous area formed from rapid solidification in the center of the welds.

2.4.6. Gaps

His measurement Depend on the comparing the size of nugget and the variable value of the current and the force of the electrode , to calibrated the characterization of the spot welding and compare the cycle of failure fatigue with the parameters of the spot welding that determine the quality of nugget

2.5. An effective quality assessment method for small scale resistance spot welding based on process parameters [10]

2.5.1. Introduction

Small scale resistance spot welding (SSRSW) is an effective method to join small-scale parts and is ever-increasingly used in man made product manufactur ing and assembly, providing mechanical support and integration, electrical connectio n, optical coupling, environmental protection and so on

2.5.2. The gool

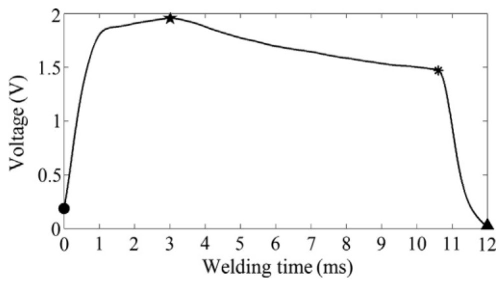
This paper performed a systematic research on the voltage curve, which turned out to be an indication for weld quality of SSRSW

2.5.3. The method

The voltage was monitored during the welding process by (DAQ) system, At last the signal was evaluated by a Matlab program. the 2-plylap welds was TC2 titanium alloy, The spot welding tests were performed using a resistance spot welding machine produced , The HF27 power supply can provide constant current, constant voltage and constant power modes for a welding process.

2.5.4. The result

Interpretation of dynamic voltage curve



Voltage waveform.

Correlation between welding quality and voltage curve

2.6. Critical Nugget Diameter of Resistance Spot Welded Stiffened Thin Plate Structure [11]

2.6.1. Introduction

Stiffened thin plate structure which is mostly applied to the car body structures consists of frame and sheet. Welding heat and pressure will make the joined metal melt and fuse to form nuggets. two distinct failure modes were observed during static tensile-shear testing: interfacial failure (IF) and nugget pullout failure (PF).

2.6.2. The gool

to determine the critical nugget diameter of the unequal sheet thickness resistance spot welded carbon steel by using failure mode investigation and compare to nugget diameter of AWS formula.

2.6.3. The method

Three pairs of mild steel SS400 plates were joined in a lap joint by resistance spot welding
Standard metallographic procedure was used to prepare macrostructure specimen
The hardness of the weld nugget, HAZ (heat affected zone), and the base metal were measured using microvickers methode on the metallographic specimens with a load of 500 g.
The tinsile – shear tests sample

2.6.4. The result

the thicker plate generates the higher welding heat and fusion zone size. This condition led to unbalance heat on joined sheet of the stiffened thin plate structure. Consequently, the asymmetrical weld nugget will be formed, where the nugget size and depth of penetration of the thinner plate side are smaller than those of thicker plate side.
The heat unbalance would be occurred when different thickness of the same materials, simillar thicknesses of different materials, or a combination of the two were joined using resistance spot welding
The microhardness of weld nugget was found to be higher than that of HAZ and raw material.
that increasing welding voltage led to increasing nugget diameter

2.6.5. Conclusion ¨

The spot weld nugget of the stiffened thin plate structure joint were asymmetric form due to the difference in electrical resistance of joined materials.
Increasing welding voltage made the shear load bearing capacity of RSW joint increase.

2.7. Resistance Spot Welding of Dual-phase Steels: Heat affected zone softening and tensile properties [12]

2.7.1. Introduction

Resistance spot welding is extensively used in automotive manufacturing and is also a favorable method for joining DP steels.

HAZ-softening has been reported to deteriorate the mechanical properties of DP steel welds

2.7.2. The gool

the main challenge in welding DP steel is to overcome the inconsistent failures encountered in the heat-affected zone and/or the fusion zone (nugget) in higher grades of DP steel spot welds.

2.7.3. The method

The microstructure of any weld is a key feature in determining its strength and formability.

HAZ Softening has been measured in various grades of DP steels;

Scanning electron microscopy showed the degree of microstructural transformation that occurred in the SCHAZ in the welds of various DP grades.

Lap-shear tensile testing is used for assessing weld performance of the spot welds.

2.7.4. The result

The characteristic of the tempered structure in DP steels was also found to be a function of chemistry. DP steel with richer chemistry formed finer cementite compared to lean chemistry steel.

2.7.5. Conclusion ¨

HAZ-softening was observed in higher grade of DP steel and was more pronounced in DP980 grade spot welds due to tempering of BM martensite, which was attributed to higher volume fraction of martensite in it.

comparing different grades of DP steel spot welds indicated that the failure mode changed from IF to full PO mode at a lower weld nugget size in DP980 compared to that in DP780. The lower critical nugget size in DP980 steel was attributed to the higher extent of softening. However, it is believed that the softening in DP980 steel promotes strain localization at the SCHAZ and premature failures.

3. Acoustic emission (AE) during welding processes

3.1. Basic theory of acoustic emission

Acoustic emissions are essentially elastic stress waves, generated by a rapid release of energy from a localised source within a stressed material [13]. The event at the source causes a release of energy which propagates in the form of a transient stress wave. This wave propagates through the material, until it reaches the sensor. The sensor converts the small surface displacements into an electrical signal, which is transmitted to a nearby pre-ampfilier and subsequently to the signal-processing equipment.

Depending on the source, the frequency of the waves extends from tens of kHz up to tens of MHz [14].

3.2. Terminology

Terminology is based on that outlined in ASTM E1316 [15].

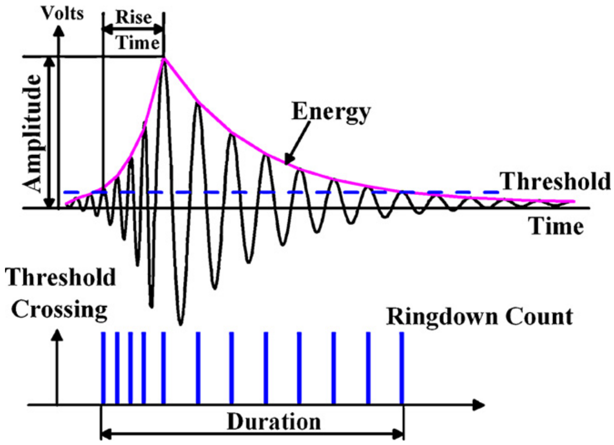


Fig 3.1. Method of extracting AE parameters [15]

AE: The class of phenomena whereby transient elastic waves are generated by rapid release of energy from localized sources within a material, or the transient waves so generated. Other terms used in AE literature include
(1) stress wave emission, (2) microseismic activity, and
(3) emission or AE with other qualifying modifiers.
AE amplitude: Peak amplitude of AE signal during signal duration.
AE count: Number of times AE signal exceeds preset threshold level during any selected portion of a test. Count is affected by dead time. Ringdown counting is used for continuous emission, and event counting is used for burst emission.
AE event: Local material change that gives rise to an acoustic emission.
AE rms: Rectified time-averaged AE signal, measured on linear scale and reported in volts (root mean square (RMS) voltage).
AE signal: Electrical signal obtained by detection of one or more acoustic emission events.
AE signal duration: Time between AE signal start and AE signal end. AE signal start is the beginning of an AE signal recognized by the system processor, and AE signal end is the last signal crossing the threshold above the threshold.
AE signal rise time: Time between AE signal start and peak amplitude of that AE signal.
Dead time: Any interval during data acquisition when the instrument or system is unable to accept new data for any reason.
Event count :AE counting method that counts each event.
Source location: Includes zone location, computed location, and continuous location.
Threshold, voltage: Voltage level on an electronic comparator such that signals with amplitudes larger than this level will be recognized.
During the welding process two types of AE signals appear: useful signals and disturbances. The disturbance signals are various noises.

3.3.Acoustic Emission System during welding

The AE produced during the production of a spot-weld can be related to weld quality parameters such as the strength and size of the nugget, the amount of expulsion, and the amount of cracking.

The resistance spot-welding process consists of several stages. These are the set-down of the electrodes, squeeze, current flow, forging, hold time, and lift-off. Various types of acoustic emission signals are produced during each of these stages.
During current flow, plastic deformation, nugget expansion, friction, melting, and expulsions produce AE signals.
The signals caused by expulsion (spitting or flashing, or both) generally have large amplitudes and can be distinguished from the rest of the acoustic emission associated with nugget formation. Fig. 2 shows typical AE response signals during current flow for both dc and ac welding.
Following termination of the welding current, some materials exhibit appreciable AE noise during solidification which can be related to nugget size and inclusions. As the nugget cools during the hold period, AE can result from solid-solid phase transformations and cracking. During the lift-off stage, separation of the electrode from the part produces signals that can be related to the condition of the electrode as well as the cosmetic condition of the weld [16].

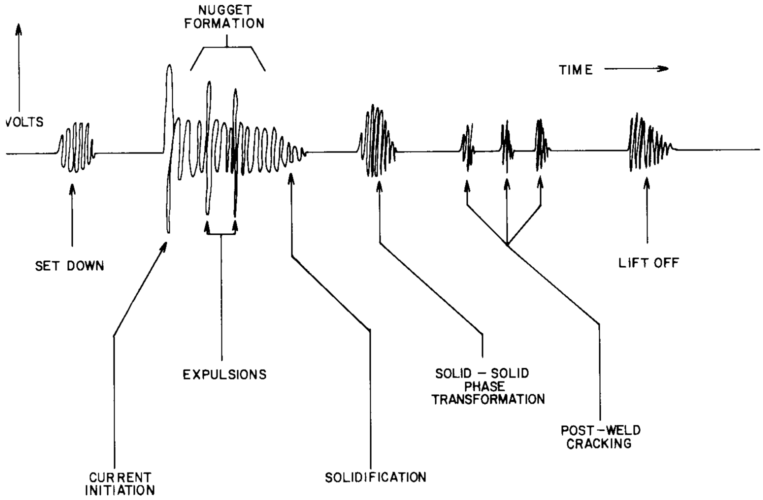


Fig 3.2.

3.4. Characterization of nugget nucleation quality based on the structure-borne acoustic emission signals detected during resistance spot welding process [17].

Luo Yi, Li Jinglong, Wu Wei, Characterization of nugget nucleation quality based on the structure-borne acoustic emission signals detected during resistance spot welding process, *Measurement*, Vol. 46 (2013), 1053–1060.

3.4.1. Introduction

Resistance spot welding (RSW) is widely used in automotive body assembly process. There are thousands of spot welds on an automobile body, The strength of spot weld largely depends on the nugget dimension.

3.4.2. The gool

This article is about evaluation of the characterizations of welding process, the characterizations of the effect of welding parameters to nugget nucleation, the characterizations of the nugget quality by the analysis of acoustic emission signals and the characterizations of the nugget quality by the analysis of tensile-shear strength.

3.4.3. Material and method

The materials used in experiment are 2024 aluminum alloy.

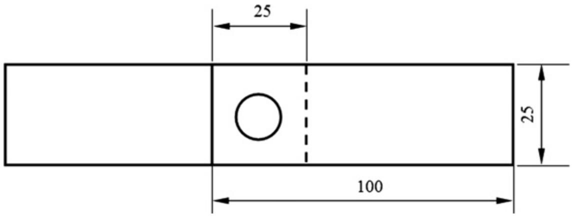
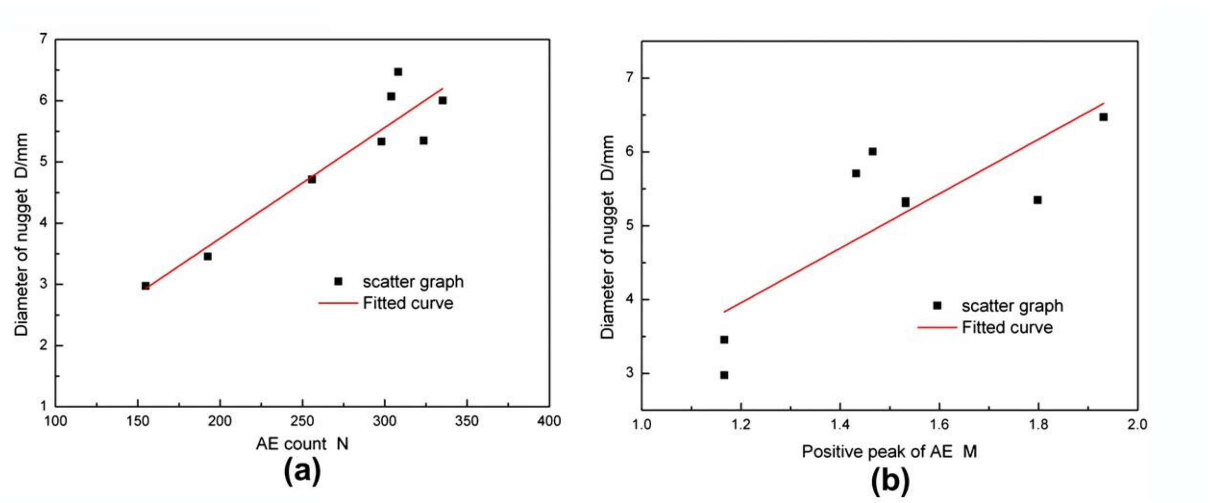


Fig. 2. Specimen specification.

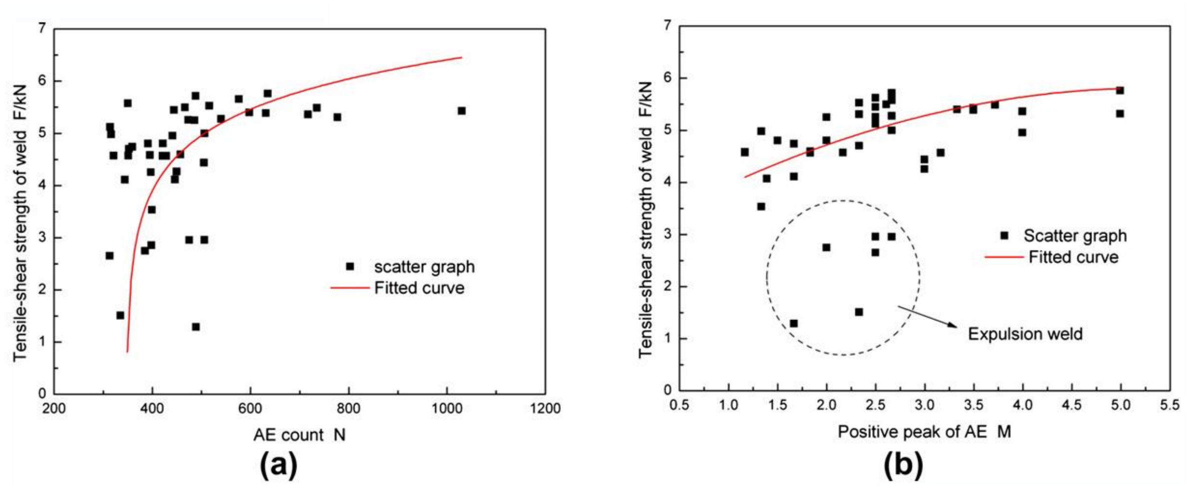
By the resistance spot welding machine the two specimens are welded overlay by 25 mm lengths, as shown in Fig. 2. The AE signals in welding process are monitored in real-time.

3.4.4. Result



The relationship between the nugget diameter and AE count, and the relationship between the nugget diameter and positive peak of nugget nucleation event.

the relationships of the nugget dimension and the characteristic parameters of AE signals present a nearly positive correlation. However, the spot weld strength does not depend entirely on the nugget dimension due to the microstructure, expulsions and defects. Because of the above factors, the relationships of tensile-shear strength of weld and characteristic parameters of AE signals present a nonlinear correlation.



Relationships between the tensile-shear strength of weld and characteristic parameters of AE signals, (a) AE count and (b) positive peak

3.4.5. Conclusion

The nugget nucleation in resistance spot welding process can be characterized by the AE signals.
The expulsion event and cracking event in resistance spot welding can be distinguished by the AE count and positive peak of AE signals.
The effect of welding current and current duration variation to nugget nucleation can be characterized by the of AE signals.
The relationship of tensile-shear strength of weld and AE count is more in line with the logarithm equation, and the relationship of tensile-shear strength of weld and positive peak of AE signals is more in line with the polynomial equation.

3.4.6. Gaps

He supposed and deduced that the relationship of tensile-shear strength of weld and AE count more inline with the logarithm equation $y=\ln(a+bx)$ where the parameters a and b can be calculated separately by fitting method.

3.5. MONITORING OF RESISTANCE SPOT WELDING BY AE [18]

3.5.1. Introduction

Resistance spot welding (RSW) is a method which has been widely used in automotive industry for decades for the welding of metal tin sheets. In terms of use and control, it is a relatively direct production process.
Acoustic Emission is a passive technique for detecting signals occurring in the materia exposed to thermal changes and mechanical strain. The key benefit of the AE technique is that the AE signal is transmitted through the material and the welding electrodes to remote areas where the sensors are safely protected from the effects of welding.

3.5.2. The gool

to confirm possibility to evaluate RSW process state based on analyses of continuous AE signals during current flow.

3.5.3. Material and method

portable RSW gun with jaw crank action, specimens of standard dimensions, The Rogowsky coil was used to measure the welding current, The resistance spot welding process consists of the following phases: the set-down ofthe electrodes, the squeeze, the current flow, the hold time or forging, and the lift off.
During the current flow, continuous acoustic emission signals can be measured

3.5.4. Result

During RSW of DC01 mild steel sheets, no strong acoustic emission was detected after welding that could be attributed to microstructural changes during the cooling of the weld joint or to cracking.

3.5.5. Conclusion

the analysis of the acoustic emission signal provides useful information on nugget formation.
The prediction of the expulsion during RSW can be improved with regard of other characteristic values of AE signal like mean, standard deviation and kurtosis of the short signal periods in defined time intervals. With simultaneous calculation of signal frequency spectrum and mentioned characteristic values the expulsion of the material can be predicted in a very short time interval before its occurrence.

3.6. Effect of welding heat input to metal droplet transfer characterized by structure-borne acoustic emission signals detected in GMAW ,[19]

3.6.1. Introduction

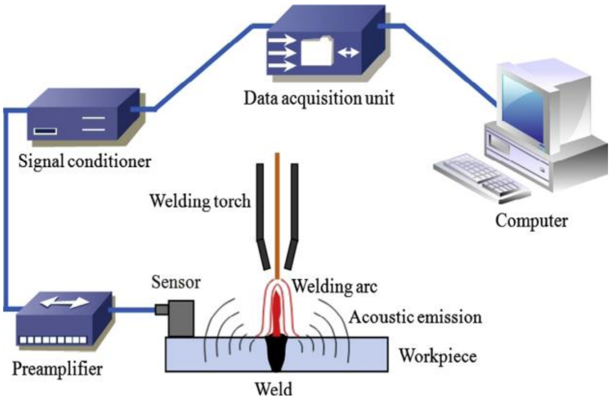
Gas metal arc welding (GMAW) is widely used in manufacturing due to its high deposition efficiency and automatable equipment with better welding quality. The welding parameters affect the MDT mode as well as the weld quality in GMAW The observation showed that the unstable welding behavior was due to the instability of a column of metal droplet generated at the wire tip

3.6.2. The gool

to promote the stability of MDT,

3.6.3. Material and method

according to the structure-borne acoustic emission (AE) signals detected in GMAW on aluminum alloy, the analysis of time domain and frequency domain were introduced, and the energy gradient was used to analyze the characteristics of metal droplet transfer..
During the current flow, continuous acoustic emission signals can be measured



Schematic diagram showing experimental equipment.

3.6.4. Result

the waves of AE signals detected in GMAW at different welding parameters, The quantity of metal droplets transferred into molten pool in unit time was called MDT frequency, the change of welding heat input is dependent on the welding parameters, such as welding current, arc voltage and welding speed. It also showed that the influence of welding parameters on the metal droplet transfer or the microstructure of weld metal can be characterized by welding heat input. .

3.6.5. Conclusion

It is possible to study the metal droplet transfer of GMAW by the analysis to the AE signals detected in welding..
The distribution of power spectrum of AE signals for metal droplet transfer was different according to the welding heat input variation.

3.7. Use of AE monitoring in laser cutting and resistance spot welding [20]

3.7.1. Introduction

Laser cutting and resistance spot welding are frequently used techniques in automotive industry and production of white goods. Similarly acoustic emission is a promising technique for monitoring resistance spot welding (RSW) process. RSW is a method which has been widely used in automotive industry for decades for the welding of metal thin sheets. Acoustic Emission is a passive technique for detecting signals occurring in the material exposed to thermal changes and mechanical strain. The key benefit of the AE technique is that the AE signal is transmitted through the material to remote areas where the sensors are safely protected from the effects of cutting and welding.

3.7.2. The gool

monitor process quality of laser cutting and resistance spot welding based on measured AE signals

3.7.3. Material and method

During the laser cutting process a turbulent flow of the cutting gas produces continuous AE signals.
Similar effect of laser cut quality on measured AE signals can be measured when changing distance between the laser-beam focal point and the sheet surface during laser cutting.
The resistance spot welding process consists of the following phases: the set-down of the electrodes, the squeeze, the current flow, the hold time or forging, and the lift off.

3.7.4. Result

The measured results confirm that laser cut quality based on measured AE signals could be predicted.
the amplitude value of an AE signal is a very suitable parameter for the evaluation of the laser-cut quality.
Also continuous AE signals during current flow in RSW are analyzed. Selected welding parameters often cause excessive energy input, that assure better reliability of fully penetrating welds even in the case of process deviations.
Continuous AE signal during RSW can be divided into tree time periods:
- time period before expulsion
- expulsion of the material
- time period after expulsion

3.7.5. Conclusion

The investigation conducted on laser cutting showed that a good agreement between the quality of a laser cut and the captured acoustic emission signals exist.
Measurements show that increased energy input to the cutting front results in a lower AE activity with lower amplitude values of voltage signals, which is a result of less or even no dross presence.
the possibilities of optimising the welding parameters and predicting the quality of the weld.

4. Analysis and evaluation of references

- Acoustic emission surveillance of spot-welding can take two forms, namely, monitoring and control. The purpose of on-line monitoring is to identify and segregate unacceptable welds for quality evaluation purposes. On-line control, on the other hand, utilizes the AE instrumentation to complete a feedback loop between the process and the source of welding current by automatically adjusting one or two process variables to compensate for deteriorating welding conditions.
- The physical phases of nugget nucleation in resistance spot welding process can be characterized by the AE signals. The expulsion event and cracking event in resistance spot welding can be distinguished by the characteristic parameters such as AE count and positive peak of AE signals detected in welding process.
- The characteristic parameters of AE signals show a better relevance to the nugget dimension and tensile-shear strength of weld.
- Preliminary results indicate that, as the nugget diameter and penetration increase in welding process, the AE count and positive peak of AE nugget nucleation event detected in welding process will increase.

- to confirm The relationship of tensile-shear strength of weld and AE count ,
- to confirm the relationship of tensile-shear strength of weld and positive peak of AE signals .

5. stage and the time of the research

The project solution will be divided into stages, each of which includes several activities and they follow each other respectively.

1. An introductory part of the project collects the experimental data, using acoustic emission laboratory equipment in cooperation with VUT, And cooperation with dakel compony .These experimentally obtained data will be evaluated, and changes in the parameters of acoustic emission signals will be assigned to a specific type of damage.
2. The second stage will be the establishment of a limited set of monitored parameters, The aim is to reduce the complexity of measurement.
3. The following stage is to verify the validity of the assessment results through extensive measurements using the required devices for different parameters of the spot welding process.
4. In the parallel implementation of the proposal, there will be a simplified designing process of electronic equipment for data capture development and evaluation software.
5. The novelty of the proposed solution lies in a totally new concept for mobile diagnostic tool, that allows to use other methods with greater sensitivity of detection of defects.

6. Objectives of the research

The aim of the present work is to develop an efficient procedure for processing the informative parameters of AE signals formed in the course of RSW and synthesize a criterion of the quality of spot-welded joints. The monitoring and improving the quality of spot welds are an ongoing process in RSW research.

- recording the signal of acoustic emission online during resistance welding spot
- analyzing the signal to determine the details of information about welding process
- monitoring and measuring the specimen on tensile resonant fatigue by acoustic emission
- to determine the life time and monitor crack propagation and the quality of nugget
- comparing the result from the second experiment with the analysis data of acoustic emission make schedule of the quality of nugget corresponding to acoustic Emission response
- find the procedure to evaluate the quality of nugget during the spot welding by AC

7. Hypotheses and point Question .

- The purpose of on-line monitoring a spot-welding process by AE is to identify bad welds or parts. This information can serve as a basis for acceptance or rejection, or for establishing a schedule for repair. Theoretically, any one, or a combination of two or all three, of the weld quality parameters described in this practice can be used for this purpose.
- Selection of the parameters should be done by determining the most prevalent causes of defective welds in a particular welding application. Excessive post-weld cracking

due to material properties, varying nugget volumes due to loose tolerances of the dimensions and surface conditions of the welded stock, and burning or excessive expulsion due to over welding can be identified as randomly occurring defects by the corresponding AE response.

- Elastic region will have higher intensity of AE signals than in plastic region.
- **Question** :
  - what the suitable way for acoustic emission to determine the size of nugget
  - How large are variations of resistance spot weld sizes,
  - How accurately can numerical models predict resistance spot weld sizes?

8. Analysis of the method

8.1.Advantage

8.1.1. Acoustic Emission

- High sensitivity.
- Early and rapid detection of defects, flaws, cracks etc.
- Real time monitoring.
- Cost Reduction.
- Defective area location: only critical defects provide sustainable Acoustic Emission sources.
- Minimization of plant downtime for inspection, no need for scanning the whole structural surface.
- Minor disturbance of insulation.

8.1.2. Resistance spot welding.

- Fast.
- Easy automation.
- Cheap.

8.2.The proplem that we face in the work (disadvantages drawbacks)

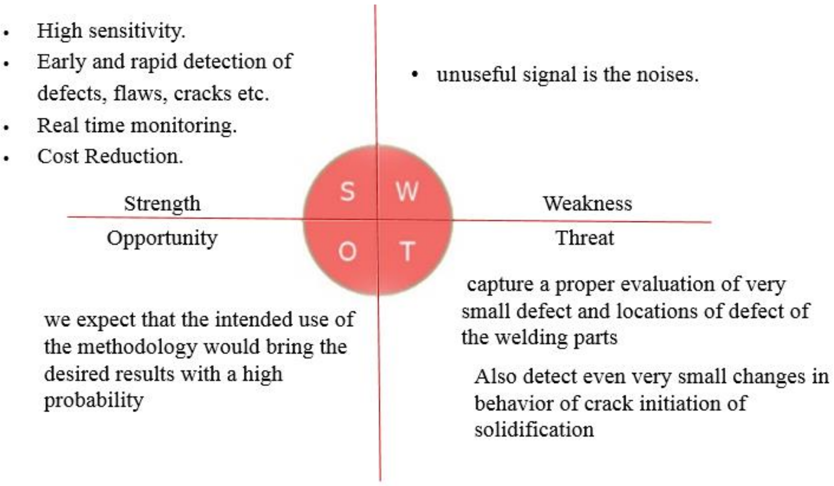
8.2.1. Acoustic Emission:

- unuseful signal is the noises.
- The greatest risk we consider reliable capture a proper evaluation of very small defect and locations of defect of the welding parts. Also detect even very small changes in behaviour of crack initiation of solidification; we expect that the intended use of the methodology would bring the desired results with a high probability.

8.2.2. Resistance spot welding:

- Electrode deposit on the weld.
- Cracks and porosities.
- Weld size.
- Necessity of access from both sides of the joint.
- Difficulties to know about the quality of the welds.

8.3.Analysis SWOT



9. Experiments

In a part of experiments, we had a possibility to use the new AE analyser called DAKEL IPL. It is a state-of-the-art system for continuous recording and processing of data from the acoustic emission sensors, 5-channel recording.

Fig. 9.1. the new AE analyser DAKEL IPL

The AE signals in welding process are monitored in realtime, where the piezoelectric sensor is mounted on the wall of electrode as shown in Fig. 4.1. The AE signals are transferred to the computer for further processing and analysis.

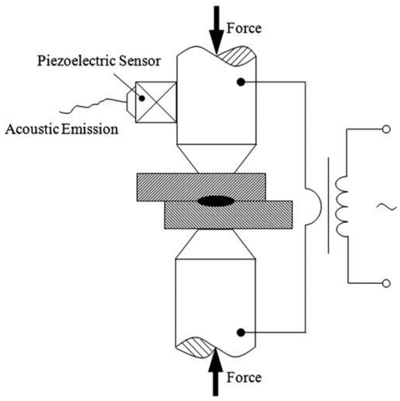
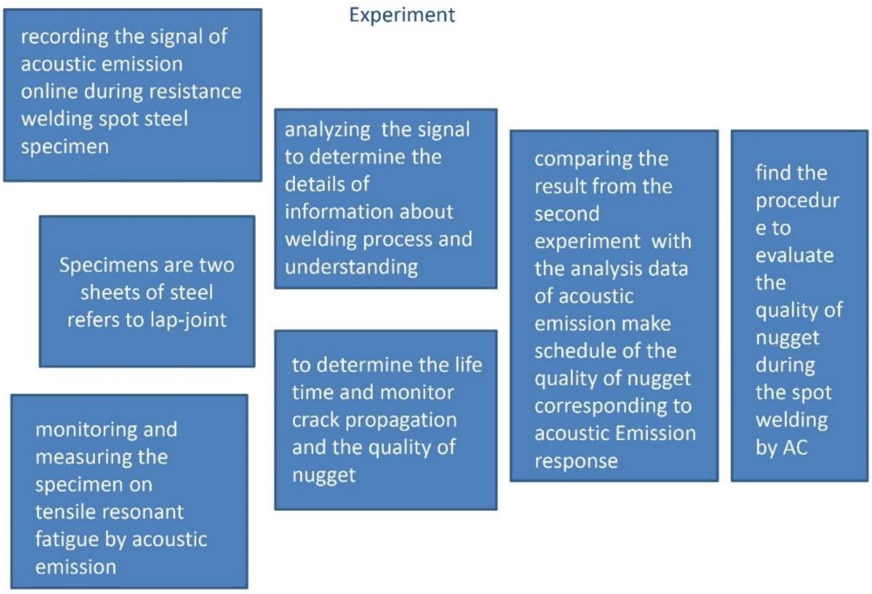


Fig.4.3. Diagram of reistance spot welding and ensor amount

Fig.4.5. Schematic of acoustic emission resonant tensile fatigue setup

10. Solution suggestion



11. Collaboration with other institutions.

Dakel company, mendelova university.

It is Supposed by TAČR

12. Anticipated costs associated with dealing with their resources

Staff costs : Wages of the individual workers with the employment relationship, including compulsory social security contributions and health insurance.

Cost of services : the payment to production of certain measuring devices will be expedient ordered from external suppliers.

Protection of intellectual property : The cost of protecting intellectual property associated with certification expected welding testing methodology developed mechanisms using test equipment.

Other operating expenses + travel : Purchase the supplies is necessary to carry out research and development work (stations, media for data backup, small laboratory equipment, etc.) to travel and contact with other project participants. There is international conference in the Czech Republic

Otherindirect costs-overhead : Faculty determines overheads FME BUT annually. Usually they are for 19.5 to 20%. Administration, infrastructure, energy, etc.

index	unit	Year			total
		2016	2017	2018	
Staff costs	Kcz	500 000	500 000	500 000	1500000
time	man-year	1	1	0,5	2,5
Average personnel costs for the time	Kcz	500 000	500000	1000 000	2000000
Cost of service (subcontracting)	Kcz	100000	100000	100000	300000
The cost of protecting intellectual property	Kcz	0	20000	0	20000
Other operating expenses	Kcz	100000	100000	100000	300000
Other indirect costs-overhead	Kcz	160000	170000	140000	470000
total	Kcz	860000	890000	840000	2590000

Table 3.1. the cost during three year

13. Characteristics of the expected result dissertation solutions in the categories defined for basic research

Name of Journal	Impact factor	5 year Impact factor
Tribology International	1,536	1,802
Tribology Letters	1,743	1,816
Wear	1,913	1,382

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