Investigation on strength of resistance spot welding joint of copper and brass using various filler materials

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Abstract. Copper and Brass are widely used in Auto electrical industries due to their good electrical conductive properties. This is possible as free electrons in metals can move through, allowing metals to conduct electricity. Resistance spot welding process (RSW) is the highly preferred welding process especially for electrical connector terminals because of its reliability over Copper and brass joints and attained importance in automotive sectors. Present work is focused on the behavior of various filler materials used in between Copper and Brass in resistance spot welding process by which the strength of weld joints is being analyzed.

1. Introduction

Expectations of Automotive industries on Quality levels are in uptrend as Industries are moving towards world class Quality. In order to meet customer expectations like joint strength, surface quality, dimensional stability, with desired processes with excellent capabilities and with robust controls, improvements via optimized cost are always preferred [1]. In this manner improvement in welding of Auto electrical joints is always under study and analysis for various factors and this is one among all. Resistance spot Welding is a thermo-electric process where heat is generated at the interfacing of two different parts to be joined by passing an electrical current through under a controlled pressure and time.

RSW is heat generation process and passing of electrical current generates through a resistance. Electric current is passed between electrodes which in turn have contact over the parts to be joined. Adding pressure under desired condition with time limitation will yield welding of joints. Resistance spot welding is the preferred welding process of joining two dissimilar materials of electrical terminal parts. This process is preferred because of its simplicity in designing the process parameters and determining the controls to the maximum extent possible like energy sensing combining all inputs and outputs together. The key factor which determines the performance of the weld joints is the strength of joints through which the electric current passes and activates the system. This strength is most important one to ensure proper connection on terminals between two parts and no weak joints and flaws are permitted. These dissimilar joints may have to withstand external factors like movement of wire braid or connectors with respect to their positions during assembly which gives additional stress to the joints [2].
Strength of joins basically depends on the penetration of base materials with each other and the internal structure which are joined [3]. These penetration can be improved with alloy coating like Zinc which increases the overlapping of metal pieces in small amount due to the applied pressure and current because of which a small portion of metal melts and solidifies together in the interface of the materials [4 & 5]. This is called weld Nugget and the strength of the joint depends how effective is the weld Nugget and it can be visualized by the peel and pull off test of joints which is a destructive test [6]. These joints will be subjected to a severe stress on field applications and the determination of the weld strength will be done by considering all factors related to fatigue, tightening torque, strength of electric current passing through that, constant or variable load being applied, etc.,.

The strength can be measured in many ways depends upon the filler wire composition requirement specified which were derived based on the real time application [7]. Basic methods of testing are peel off test and pull off test. In these tests the welded joints will be subjected to the maximum load till the joints are subjected to initial crack and then break. This will be done by various simulations and variational analysis by securely resting one base material and applying load on other one either axially or radially till the joints are broken [8 & 9]. The strength will be generally specified in Newton and or Kilogram (Kg)

2. Material selection

Copper and Brass are widely used in Auto electrical industries because of their good electrical conductive property. These materials are best suitable for Resistance spot welding as it processed by combination of Thermo-electric processes. Due to the ductility of these materials, the fusion of joints during welding will be effective when additional pressure is getting added to that.

### Table 1. Chemical composition of the base metal (Copper)

| Elements | Copper | Lead | O2 | Bismuth | Silver |
|----------|--------|------|----|---------|--------|
| %        | 99.9 Min | 0.0005 Max | 0.06 Max | 0.0001 Max | 0.03 Max |

### Table 2. Chemical composition of the base metal (Brass)

| Elements | Copper | Iron | Lead | Zinc | Tin |
|----------|--------|------|------|------|-----|
| %        | 62 - 65 | 0.07 Max | 0.07 Max | Reminder | Nil |
Copper is in the form of wire braid having desired number of strands designed according to the conductivity need based on the strength of electric current is getting passed. The wire will be of 0.13mm diameter, 7 ropes and 3 ropes with 61 strands per rope. All put together more than 1000 strands. Ends of the wire will be fused together for desired length and width according to the weld joint dimensions. These end fusion normally done by hot stacking of wires ends together in a constrained cavity like fixture to get the desired shape. Number of cuts of wire is permissible in terms of percentage which depends upon the applications. But care should be taken that fused ends are not having any cut or loose wires which in turn reduces the strength of joints.

Terminal is made out of Brass which is getting welded with Copper wire. Brass is the alloy of copper and Zinc. By varying the compositions of Copper and Zinc, the mechanical properties of Brass can be changed. Here we selected Brass with 30 to 40 % of Zinc as the electrical and thermal conductivity will be good. Terminal will be stamped from the rolled Brass sheet with a thickness of 1mm. These sheets will be passed through the progressive stamping tool where the shape and dimensions are gradually formed and trilled to get the desired dimensions. The surface of Brass Terminal should be flat and not to have any cracks and heavy dent marks which in turn have impact on the weld strength as the contact of fused wire during welding may get deviated from the actuals.

2.1. Material testing
Selected material is tested for its chemical composition as per American Society of Testing and Materials (ASTM) standard to get confirmation about the elements present in the Copper and Brass.

### Table 3. Chemical composition of the base material (Copper) measured

| Elements | Copper | Lead | O2 | Bismuth | Silver |
|----------|--------|------|----|---------|--------|
| %        | 99.96  | Nil  | Nil| Nil     | Nil    |

### Table 4. Chemical composition of the base material (Brass) measured

| Elements | Copper | Iron | Lead | Zinc     | Tin    |
|----------|--------|------|------|----------|--------|
| %        | 64.475 | 0.028| 0.024| Reminder | Nil    |

### 3. Filler materials

Filler materials are the materials added between the base metals to form the junction between them. These alloy materials will have lower melting points than the base metals. These filler alloy materials melts and freezes at a single temperature that is lower than the melting points of the base metals.

Many varieties of filler materials are available according to the base metals used for welding. Most of them are alloying materials suitable for many base metals like, Copper, Brass, Aluminium, Carbide, steel, etc., Filler alloy materials available for even joining similar dissimilar metals like Copper with Copper and Copper with Steel.

#### Filler alloy materials types

- Silver Phosphorus- SILFOS
- Copper alloys
- Copper Phosphorus alloys
- Nickel filler materials
- TIN paste
- Carbide brazing alloys
- Silver based cadmium metals
- Soldering alloys

#### 3.1 Silver Phosphorus

The Silver content in SIL-FOS Alloys varies from 16% to 2% and the percentage of silver and phosphorous have significant change in the melt and flow characteristics of the filler material. These alloys are Copper-based metals which are self-fluxing on copper by virtue of the presence of phosphorous.
But material is not suitable for ferrous or nickel based materials because the joint will become brittle and may get failed.

### 3.2 Copper alloys
Copper brazing alloys have high corrosion resistance, electrical and thermal conductivity. Copper is ductile, and has excellent joint penetration. Copper alloy brazing can be done in both suction and atmospheric furnaces, and can be used to braze many different metals. Larger gap will result in a weaker braze joint.

### 3.3 Copper Phosphorus alloys
These alloys are Copper-based materials which are self-fluxing on copper by virtue of the presence of phosphorous. The level of phosphorous has impact in the ductility of the material. The percentage of phosphorous in the filler metal is directly proportional to the fluidity of the material. It is not recommended to use on ferrous or nickel based materials because the joint will become brittle and may get failed.

### 3.4 Nickel filler materials
Nickel-based materials are suitable for joining stainless steel and Ni based alloy metals. Diffusion of melting point goes into the base metals during the welding process. These brazing alloys are best suitable for brazing and heat treating combined operations.

### 3.5 TIN paste
Tin silver solder paste contains filler metal, soldering flux with a binder for a combined application. These pastes are readily available and adoptable for both manual and automated production operations.

### 3.6 Carbide brazing alloys
Carbide brazing alloys are used for brazing carbide and diamond cutting tools. These materials include nickel or manganese to enhance wetting of the carbide in turn increases the bonding strength. These alloys consist of multiple layers especially two of brazing filler metal joint onto a core of copper. This relieves the stresses arise because of differences in thermal expansion between the carbide and base metal.

### 3.7 Silver based cadmium metals
These alloys are low-temperature, free-flowing filler metals preferred for joining both similar and dissimilar metals. Joints produced by these materials are very strong, ductile and are safe because cadmium-free materials.

### 3.8 Soldering alloys
Soft solders are filler metals used for low temperature applications. These are typically available in the form of wire or flux. Soldering alloys are available in lead, tin, copper, silver, and other compositions and can be converted into wire, strip, paste, powder or required shapes.

### 4. Experiments and Evaluations
Fig 3 & 4 shows the actual parts - Copper wire and Brass Terminal which are joined together in RSW process. Fig5 shows the assembly in welded condition as Copper wire is joined with Brass Terminal in RSW. Terminal and wire are oriented properly in the fixture made for the welding assembly.
Figure 3. Copper wire for connector Terminal.

Figure 4. Brass Terminal as connector.

Figure 5. Resistance spot welded joint
Welding fixture made of insulated material which can resist heat is used for welding the joints. This fixture consists of a base plate with locators to suit wire and Terminal orientation features in order to locate and orient the part as per the requirement. Base of the fixture is directly connected to the bottom copper electrode. The electrolytic Copper electrode is fixed in the top ram through which welding is done. This ram will have direct contact on the wire placed over the Terminal and apply current and pressure.
The pressure is exerted by pneumatic actuator which is connected to the top electrode. As the cycle starts, the ram comes down in determined speed and applies pressure over the joints to be welded. Simultaneously the current passes through the electrodes for determined time. These combined actions increases the temperature at the joint portions and the metals are transformed to plastic stage and welding takes place. The ram retracts once the cycle completes and joint to be air cooled in atmospheric temperature and no rapid cooling is permitted which may create surface defects and weaken the joints.

5. Experiment without filler material

Initial experiment conducted to understand the strength of weld without filler material. In this trial no filler material is used and RSW made directly between Copper and Brass metals. The process parameters are optimized in order to get the effective strength targeting the highest load. Parameters are set and locked with this trial and no change is planned as the exercise is to compare the strength of weld with various filler materials.

5.1 Observations- Without filler materials

![Weld Strength Chart](image)

**Figure 9.** Weld strength on joints without filler material

Weld strength observed between 10 to 20 Kg. There is a variation up to 10Kg is found. The process capability is found not to be in line because of the variation which may lead to a weaker joint as against the specification target of 25Kg min. 9 samples are selected for each experiment and comparison. The weld nugget observed to be with lesser penetration between base metals and the fusion of metals found to be in adequate.

The weld strength test carried out in peel off method using dedicated fixtures and tools. The Copper wire fusion is not adequate as the bare end fused Copper segments didn’t get collapsed during testing. Deformation noticed in the Brass plate as it is due to the external pressure given by the pneumatic actuator.
5.2 Observations- with filler material- Silver phosphate

Subsequent experiment conducted to understand the strength of weld with filler material. In this trial Silver phosphate is used as filler material between base metals and RSW made. Same process parameters are optimized in order to get the effective strength. Filler material used here is the alloy material with Silver as 16% and it has low melting point than the base metals.

![Weld Strength Graph](image)

**Figure 10.** Weld strength on joints with Silver phosphate filler material

Weld strength observed between 25 to 35 Kg. There is a variation up to 10Kg is found. The process capability is found not to be in line because of the variation which may lead band shifting risk factor which may end up in a weaker joint. But in this case the actual strength is higher than previous one and it meets the specification target of 25Kg min. 9 samples are selected for each experiment and comparison.

The weld nugget observed to be with better penetration between base metals and the fusion of metals found to be adequate. The weld strength test carried out in peel off method using dedicated fixtures and tools. The Copper wire fusion is adequate as the bare end fused Copper segments got collapsed during testing.

Deformation noticed in the Brass plate as it is due to the external pressure given by the pneumatic actuator.

5.3 Observations- with filler material- Tin coating

Next experiment conducted to understand the strength of weld without filler material. In this trial Brass plate was coated with Tin and used as filler material between base metals and RSW made.
Same process parameters are optimized in order to get the effective strength. Filler material used here is the Tin with a coating of 0.03mm max and it has low melting point than the base metals.

![WELD STRENGTH](image)

**Figure 11.** Weld strength on joints with Tin coating as filler material

Weld strength observed between 26 to 48 Kg. There is a variation up to 22Kg is found. The process capability is found not to be in line because of the variation which may lead band shifting risk factor which may end up in a weaker joint. In this case the actual strength is slightly higher than previous one and it meets the specification target of 25Kg min but it getting operated closer to the minimum requirement. 9 samples are selected for each experiment and comparison.

The weld nugget observed to be with better penetration between base metals and the fusion of metals found to be adequate. The weld strength test carried out in peel off method using dedicated fixtures and tools. The Copper wire fusion is adequate as the bare end fused Copper segments got collapsed during testing.

Deformation noticed in the Brass plate as it is due to the external pressure given by the pneumatic actuator.

5.4 Observations- with filler material- Tin coating with silver phosphate

Next experiment conducted to understand the strength of weld with filler material. In this trial Brass plate was coated with Tin and used as filler material between base metals and RSW made. In addition to that Silver phosphate alloy is also used between the base metals.
Same process parameters are optimized in order to get the effective strength. Filler material used here is the Tin with a coating of 0.03mm max and Silver phosphate with 16% silver is also used and both are having low melting point than the base metals.

![Weld Strength](image)

**Figure 12.** Weld strength on joints with Tin coating and Silver phosphate

Weld strength observed between 40 to 46 Kg. There is a variation up to 6Kg is found and it is lesser compared to earlier experiments. The process capability is found to be in line because of lesser variation In this case the actual strength is higher than previous trials and it exceeds the specification target of 25Kg min.

The weld nugget observed to be with better penetration between base metals and the fusion of metals found to be adequate. The weld strength test carried out in peel off method using dedicated fixtures and tools. The Copper wire fusion is adequate as the bare end fused Copper segments got collapsed during testing.

Deformation noticed in the Brass plate as it is due to the external pressure given by the pneumatic actuator.

**6. Conclusions**

Pragmatic relationship developed out of experiments and data generated in the Resistance spot welding processes by using various filler materials.

Among four trials conducted with and without various filler materials, presence of filler material influence the fusion of base material in turn increases the weld strength. Interaction between the filler materials with the base metals predominately increases the strength of joint.
Combination of Tin with Silver phosphate have more influence on the strength. Maximum weld strength (46 Kg / 4.6N) can be achieved by the combination of Tin and SIL-FOS

7. References

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