Analysis on Effect of Nugget Quality in BIW joints through Pre-Heating Parameter in Resistance Spot Welding

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***Abstract*: A typical automotive body would have between 3500 and 4000 resistance spot welds at a nominal rate of 40 to 60 welds per minute, which is a common rate for resistance spot welding (RSW), which is widely employed in the construction of automobile bodies. To reduce weight, high-strength steel sheets are widely employed in automotive body structures. The importance of evaluating the joints' quality using these sheets justifies further research to overcome specific quality issues. The interfacial surface of a 22MNBAS AS low alloy steel sheet that has been spot welded has fractured. The impacts of welding parameters like post heating duration and post heating current on the weld quality of 22MNBAS AS low alloy steel sheet are experimentally explored in this study to lessen this disadvantage. This sort of fracture is eliminated by heat treatment through post heating in the RSW process, according to metallographic analyses and destructive testing.**

Keywords: **Resistance spot welding, 22MNBAS AS low alloy steel, Interfacial fracture**

Introduction - Resistance welding is a popular welding process due to its high speed and low-cost combination. It also provides great reproducibility One of the most important metal joining methods for high - volume manufacturing in the automotive, biomedical, and electronics industries is resistance spot welding (RSW).
Large-Scale Resistance Spot Welding, which typically involves 2 to 6000 spot welds, has taken over as the primary method of vehicle body construction.
Small-Scale Resistance Spot Welding is grabbing the interest of more and more researchers as the use of extremely thin metal sheets in the production of electronic parts and gadgets increases.
With the use of the Taguchi technique, this study proposes a method for assessing the impact of the process variables (electrode force, weld duration, and welding current) on the tensile strength of a resistance weld joint for mild steel.

Multi-variables had an impact on the Taguchi approach, which is useful for handling replies. When compared to studies using a complete factorial design, this approach significantly lowers the number of experiments needed to represent the response function. Finding any potential interactions between the factors is this technique's main benefit. The main method used to weld sheet metal in the production of automobile assembly is resistance spot welding. The incorporated infrastructure makes RSW a cost-effective technique that is also aesthetically highly appealing because to its outstanding surface quality. RSW is a procedure that, in general, involves the joining of two or more faying surfaces at a point where there is resistance to the flow of an electric current through sheets that are pressed together by electrodes.
A brief pulse of low-voltage, high-amperage current heats the contacting surfaces at the area of current concentration, fusing a nugget of weld metal together. The electrode force is maintained after the current flow stops, and the weld metal rapidly cools and solidifies. Each weld, which typically takes a fraction of a second to complete, is followed by the retraction of the electrodes.

Literature review - High-strength steels continue to play a larger and larger part in the design of vehicle bodies because materials with high formability and strength are required for the construction of automotive bodies. Asian vehicle body constructions have been using JIS 22MNBAS AS low alloy steel for a few years because it can meet the necessary formability and strength standards. There aren't many published research publications on this material's resistance spot welding. Weldability issues are a common concern with 22MNBAS AS resistance welding.
In a manufacturing line where resistance spot welding is used, interfacial cracking of these welds under peel testing has been recorded. High strength steels (HSS) and advanced high strength steels exhibit a similar issue (AHSS). To identify the causes of HSS steels' hold time sensitivity (HTS).
Destructive (peel) testing demonstrates HTS. Particularly, the spot weld breaks interfacial when peeled during normal spot-welding hold periods of 30 to 60 cycles. The weld, however, may peel with a full-button morphology for shorter hold periods (5 cycles or fewer).
They concluded that Hold time sensitivity was only seen in the transformation-hardened steel under study due to a confluence of an unfavorable stress condition (undersized welds) and a microstructure that was crack-prone.
Little indication of porosity effects could be seen in the fracture morphology, which was almost entirely trans granular cleavage.

They continued their investigation by conducting a DOE study on the variables influencing the weldability of HSSs. On DP and TRIP steels, they also investigated the concept of in-situ post-weld heat treatment. According to reports, tempering is a useful technique for lowering hold-time sensitivity (HTS) in high-strength sheet steels that can be hardened. AHSS pulsing effects were investigated utilizing experimental testing and SORPAS FEA software. They adjusted the cooling rate of the RSW and the hardness of the fusion zone and HAZ using the second pulse current.

Mill TC Material Properties & Chemical Properties for Hot Stamping material

Part Name	Grade	Std.	Supplier	Chemical Properties													Mechanical Properties		
				Properties	C	Si	Mn	P	S	Al	Cr	B	Ti	N	Mo	Ceq	Tensile Strength (Mpa)	Yield Strength (MPa)	Elongation %
				Min	0.19	0.15	1.10	-	-	0.004	-	0.001	0.020	-	-	-	500 to 700	35 to 550	Min 12%
				Max	0.25	0.35	1.80	0.025	0.01	0.070	0.50	0.005	0.050	0.015	0.35	0.41			
REINF-CTR PLR	22MNBAS AS	11-04-822	Arcelor Mittal (As per Mill TC)	Actual	0.218	0.242	1.139	0.009	0.007	0.040	0.175	0.003	0.038	0.005	0.010	0.33	555	394	24%

They concluded that choosing the right pulse sequence might maximize the weld's performance in tensile shear testing, including load to failure, displacement, and energy absorption. AHSS spot welded steels' static and impact characteristics because of the weld microstructure. They claimed that testing DP600 repeatedly resulted in interfacial failure, while testing TRIP780 and HSLA revealed partial interfacial failure, with fracture propagating through the HAZ and into the FZ at intermediate test velocities.
This study's major goal is to create workable methods for preventing interfacial fracture in 22MNBAS AS resistant spot welds. As a result, experimental research was done to determine the impacts of post-heating factors like current and duration on weld quality. For this reason, destructive tests like peel testing and metallographic studies like the Rockwell test are used to compare the metallurgical characteristics of the weld to the process parameters.

Experimental Set up

Welding machine and electrodes
A 150 kVA press-type spot welder with a constant-current controller and a pneumatic gun was used for the actual welding tests. The electrodes utilized have a 9 mm face diameter and a domed tip.
Specimen
According to the needed industrial use, a 2 mm material thickness is chosen. JIS 22MNBAS AS 400 is the kind of material employed in this research, and tables 1 and 2 reveal its chemical and mechanical characteristics.

Weld Tester
The TECNA Weld Tester TE1600 verifies the correctness of the current and force.

Peel testing
A spot weld quality test is the peel test. Qualitative data on the strength is obtained by a manual hand peel test. Additionally, it shows where there is a lack of fusion. Up to breakage, two sheets are dragged apart in a uniaxial direction. In contrast, the specimen is bent a certain distance in the tensile-peel test while one sheet is fixed in the apparatus and the other sheet is pushed in the opposite direction, allowing for the observation of the fracture that occurs. The peel testing coupons used in this investigation have dimensions of 140 x 50 mm.

Hardness testing
An effective way to gauge the hardness of the weld is to do Rockwell C hardness testing on the spot welds outside surface. These findings matched up with hardness traversals across sample joints. In this investigation, an oil removal approach is used to clean one surface of each sample before hardness testing. One Rockwell C (Rc) hardness test is run on each sample in the middle of the weld surface. These hardness tests and microhardness testing conducted across sectioned welds showed good agreement.

Experimental method
In current research, the effects of post heating current and time on interfacial fracture have been investigated. First, a weldability lobe diagram referencing JIS 22MNBAS AS 400 sheet is generated to analyses such impacts by altering welding current and welding duration.
Peel testing reveals interfacial fracture even though the biggest nugget is created when welding constants are considered. Two series of weld samples have been constructed to study hold time effects on this kind of fracture. Repeating a test number is crucial to demonstrate the weld machine's durability over time. The goal of this study, as stated in the previous section, was to create workable methods to reduce or eliminate interfacial fracture in 22MNBAS AS resistance spot welds. However, it has been shown that fractures often start near interfaces. Therefore, increasing hold duration could not be recommended as an effective strategy for lowering interfacial fracture.
The primary cause is that the weld button's high cooling rate, which is roughly equal to 103-105 per second, makes it more likely that a brittle structure will be formed. Application of post heating time and current is another way to get rid of this issue. The major goals of post-heating time and current application are to reduce weld fracture of 22MNBAS AS sheet joining and achieve high quality of residual metallurgical phases.

After			
S. No	TEST SPECIFICATION	REINF ASSY-CTR RH PLR	REINF ASSY-CTR LH PLR
1	Tensile Spec: 1300 ~ 1650MPa	1400	1360
2	Yield Spec: 1000~1400MPa	1124	1106
3	Elongation Spec: RBC - MIN 6%	7.36%	6.60%
4	Hardness Spec: 410~520 HV	474, 474, 474, 481	433, 439, 439, 441
5	Coatng Thickness Spec: 35~50 µm	Top end -38 Bottom end - 37	Top end -38 Bottom end - 37
6	Diffusion Layer Spec: Max 15 µm	Top end -8 Bottom end - 8	Top end -8 Bottom end - 7
7	Surface Roughness Spec: 1.3~5.0 µm	1.588, 1575, 1.538	1.961, 1.879, 1.832
8	Micro Structure (Martensite, Tempered Martensite or Bainite)	Tempered Martensite	Tempered Martensite

(See table 1)

The post-heating stage is typically regarded as a heat treatment technique. In this approach, a post-heating current and time are applied to the weld sample after the hold period, and these current and time are typically lower than those in the weld stage.

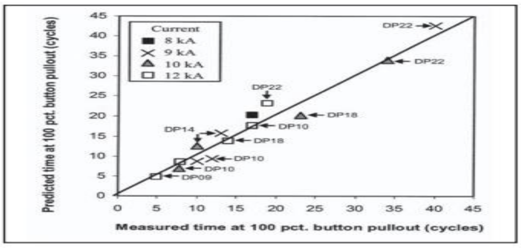
The post-heating step in spot welding 22MNBAS AS steel sheet is determined using Design of Experiments (DOE). The main welding parameters, such as post heating current and duration, are taken into consideration as design considerations with six stages while designing experiments. 36 samples of spot welds are sectioned through the nugget and polished in preparation for the Rockwell hardness test. Samples are peeled after being tested for hardness.

Results and Discussion

Effect of the post-heating period on the nugget's hardness in general, interfacial and button modes of fracture were seen during the peel test of 22MNBAS AS sheet spot welded joints. In fact, button failure mode during peel testing is preferred over interfacial fracture for high strength alloy steels like 22MNBAS AS, but 22MNBAS AS spot welded joints have a higher propensity to fracture in interfacial surface mode. All samples from two series with various holding times show interfacial direction fractures. Therefore, the post-heating stage is used to reduce nugget hardness to reduce the risk of 22MNBAS AS sheet connecting weld interfacial fracture.

Figures 1

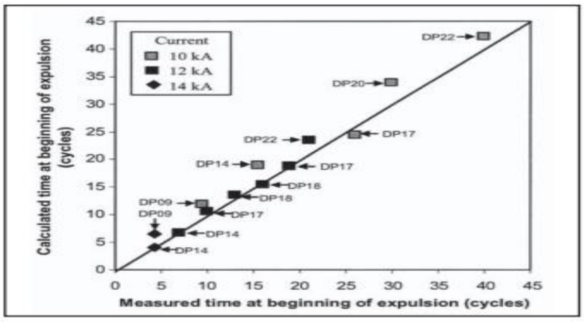
TIMER PARAMETER DETAIL FOR Spot Welding Gun	
Material Grade:DP ,TRIP,MS,Hss	TIMER NO : 2
Part No. :	ISSUE DATE
Robot No :	REV.NO. / REV.DATE
GUN MAKE : Model :	GUN TYPE
SETTING PARAMETERS	X
SCHEDULE NO.	41
SQUEEZE (cy)	25
PRE WELD-1 (ms)	0
COOL TIME 1 (ms)	0
MAIN TIME -2 (cy)	18
COOL TIME 2 (ms)	0
POST WELD -3 (ms)	0
HOLD (cy)	10
PRE WELD CURRENT-1 (KA)	0
MAIN WELD CURRENT-2 (KA)	10
POST WELD CURRENT-3 (KA)	0
FORCE (Newton)	4500
NOTE:1 TOLARANCE: NEWTON ± 300N , Arm end setting ±1 KA from the setting current	
UPDATED BY	APROVED BY Weld Specilisit
NAME Rajasekar	venkatesan V
SIGN	ms=milli second
DATE	1cy = 20 ms



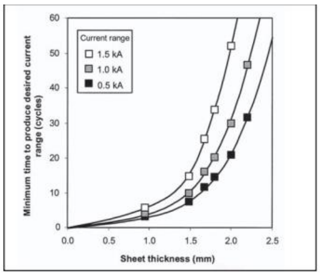
Results indicate that high strength nuggets will be produced in a short amount of time after welding (5 cycles). Increasing the post-heating time results in a higher heat input to the weld zone and a proper heat treatment process, which lowers the nugget hardness. The specimen's hardness drops to 37 Rc in just 13 times (5 kA), after which the increase lasts for another 18 cycles.

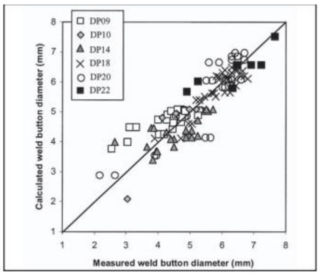
Figures 2

TIMER PARAMETER DETAIL FOR Spot Welding Gun	
Material Grade:DP ,TRIP,MS,Hss	TIMER NO : 3
Part No. :	ISSUE DATE
Robot No :	REV.NO. / REV.DATE
GUN MAKE : Model :	GUN TYPE
SETTING PARAMETERS	X
SCHEDULE NO.	42
SQUEEZE (cy)	25
PRE WELD-1 (ms)	0
COOL TIME 1 (ms)	0
MAIN TIME -2 (cy)	20
COOL TIME 2 (ms)	0
POST WELD -3 (ms)	0
HOLD (cy)	10
PRE WELD CURRENT-1 (KA)	0
MAIN WELD CURRENT-2 (KA)	11.2
POST WELD CURRENT-3 (KA)	0
FORCE (Newton)	4500
NOTE:1 TOLARANCE: NEWTON ± 300N , Arm end setting ±1 KA from the setting current	
UPDATED BY	APROVED BY Weld Specilisit
NAME Rajasekar	venkatesan V
SIGN	ms=milli second
DATE	1cy = 20 ms



The hardness of the nugget reduces gradually from 2.5 to 3.5 kA and abruptly from 3.5 to 4 kA because of the post-heating current. It decreases to its lowest value at 4 kA, then rises because of excessive heating.



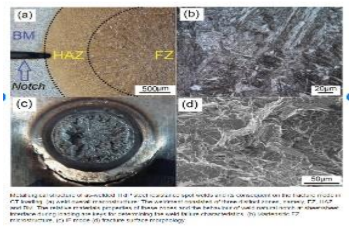


Interaction of post heating current and time on hardness of nugget the method used in the experiment's design, the results of the hardness test, and its elements' impact. It has been noted that the link between welding current and time in the post-heating stage makes it difficult to estimate the ideal parameter when just considering one number. The fifth level of variables, post-welding current, and time greatly reduced the nugget's hardness to its minimal value. By converting these levels to their corresponding values, 4 kA post-welding current and 15 cycles post-welding time appear to be sufficient to noticeably reduce the hardness of the nugget.

Figures 1 and 2, on the other hand, show how intensifying post-heating time after the fourth level and similarly intensifying post-heating current after the fifth level, leads in escalating nugget hardness. After the first holding period, the nuggets quench repeatedly because of the combination of current and duration in the post-heating step, which results in an excessive heat energy input.

The hardness of the nuggets has been reduced by using the post-heating stage, as was demonstrated in the previous section. Applying the post-heating stage is an excellent technique to cause bottom failure, according to sample peel tests (see table 1). Most samples subjected to the post-heating stage have failed using the button failure mode, apart from samples exposed to an inadequate post-heating stage, which resulted in interfacial surface fracture from insufficient heat input during the heat treatment process. Additionally, as previously discussed sections have demonstrated, increasing post-heating time and current most likely enhances nugget hardness.

Additionally, Table .2 has demonstrated that an interfacial fracture was caused by an excessive heat input when post-he ating current and time were combined at the sixth level.



Conclusion

In this study, experimental research was done to determine the impacts of post heating duration and post heating current on the weld quality of 22MNBAS AS low alloy steel sheet. The findings demonstrate that the high cooling rate of the weld button causes the nugget zone of the 22MNBAS AS sheet to become brittle, resulting in interfacial fracture. This study has demonstrated that this sort of fracture may be treated with heat by using post-heating current as a heat treatment procedure. Like post heating time, but at a lower rate, interfacial fracturing is reduced. Contrarily, increasing post-heating current and time past a critical point leads the nugget to repeatedly quench, increasing the likelihood of failure.

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