“Microstructural and Mechanical Investigation of Resistance Spot Welded DP600, TRIP780 and MS980 Steel Joints”

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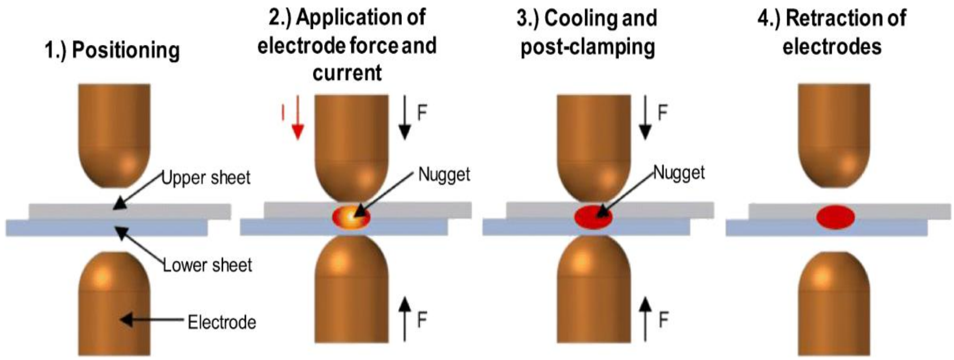
Abstract: The Advanced High Strength Steels (AHSS) (including Dual Phase (DP600), Transformation Induced Plasticity (TRIP780) and Martensitic Steel (MS980) seem to have all the qualities desired by the automotive industry - high strength, enhanced crash performance and better fuel economy. The most widely used technique to weld automotive bodies is body structures made of such steels. This welding process, however, has an important effect on the development of the microstructure and mechanical properties of the welds. targeted TRIP780 and MS980 steels. Shear in tension properties of the materials while optical and scanning electron microscopy were carried out to analyse the microstructures. heat input nugget formation, nugget HAZ characteristic and strength of the welded joints. The superior energy absorption properties were found in TRIP780 materials while the high hardness values were obtained in MS980 materials by the presence of martensitic microstructures in these materials. The findings are important for deciding the best parameters for welding in order to obtain better performance of joints for automotive applications.

Keywords: Resistance Spot Welding, DP600 Steel, TRIP780 Steel, MS980 Steel, Advanced High Strength Steel, Microstructure, Tensile Strength, Hardness

1. Introduction:

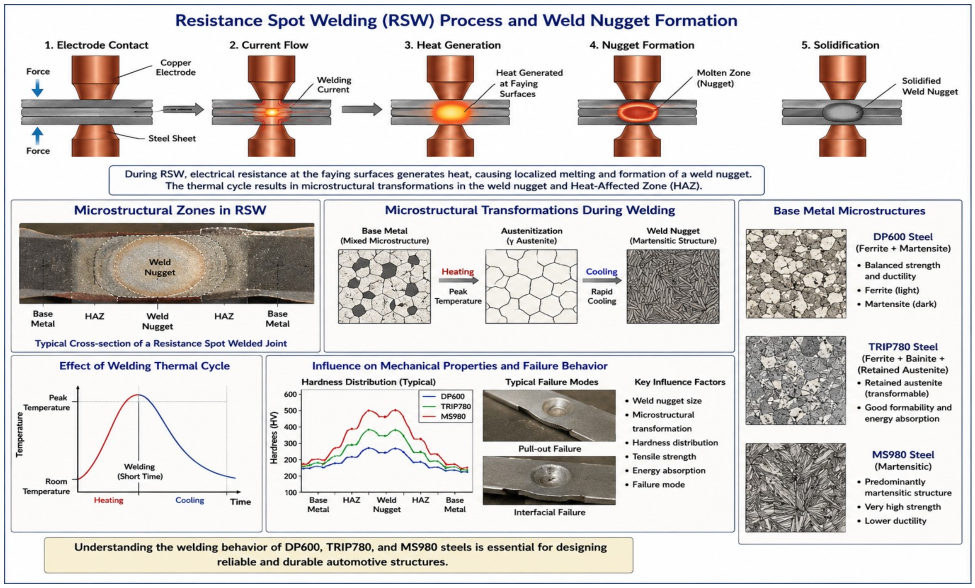
In the automotive industry, constant innovation is taking place, as researchers strive to find new materials and manufacturing technologies that will help to lighten vehicles without compromising their integrity and safety features. The introduction proven to be a good material combination of strength, ductility and formability. Amongst these steels DP600, TRIP780 and MS980 steels are more familiar in the structural elements of cars including pillar and reinforcement, crash strength and body panels etc.



Despite increased competition, (RSW) is still important joining technology for automotive production due to reasons such as: high production rate, high degree of automation and economic viability. In a typical automobile body, there are thousands of spot welds, and they are extremely important in the overall structural performance of the automobile.

During the RSW process, there is electrical resistance generating the heat and growth of a weld nugget. Continuous heating and cooling during the welding process brings about a significant modification of the microstructures of these two areas. These changes take an immediate effect.

which together provide an optimum. The energy absorption property of steel is optimum via retained austenite, which is transformed to martensite under deformation, in TRIP780 steel. At present, martensitic structure, and it has a relatively low ductility, while the strength is high. To design provided reliable, durable automotive parts and structures, the behavior of these steels through welding has to be understood.



The present work focuses on the different microstructures developed in the resistance spot welded DP600 grade, TRIP780 grade and MS980 grade steels and the related mechanical properties. The aim of the investigation is to correlate changes in that occur as a consequence property change that result.

2. Review of Literature:

Ma et al. (2008) the DP600 welded steel. During welding, significant changes were observed microstructures including weld nugget microstructure which are important for the study. Heavy emphasis on martensite steel forming, due to the fast-cooling rate after welding, which made up the bulk of weld nugget. According to the authors size of nugget, difference of hardness and mode of failure are also seen to be factors of the strength of the weld.

Gould (2009) briefly discussed other advanced high-strength steel joining technologies during the Advanced HS Steels: Different Joining Technologies paper. The emphasis of the research was placed on the problem of being suitable and dominant welding processes at the time in the vehicle industry. Based on observation the key welding parameters were noted which needs to be well controlled to produce strong and reliable welding for AHSS Materials.

Xia et al. (2010) impacts of the nugget formation. They have observed that the welding current and electrode force, significantly affect the formation of weld nuggets. Based on the study it is concluded that for every increase in welding current increases joint give an increment but if the welding current is increased beyond a certain value, it causes the expulsion and causes the quality of the weld to deteriorate.

Zhang and Senkara (2011) discussed the basic concepts and uses of resistance welding. They clarified the importance of generation of electricity, heat generation, electrode pressure and formation speed of welds when forming welds. They would find useful application in understanding application in the industrial manufacturing process.

Sun et al. have examined these different samples as described above (shown in the below figure) to determine the influence absorbed of the sample. The various parameters of the (fusion zone size and failure mode) have been tested as above and its effect has been analysed (see figure below). They discovered that bigger fusion areas will contribute to higher load carrying capacity, on average. They also suggested that the failure mode has to be taken into account as a factor affecting.

Pouranvari and Marashi (2013) reported in detail automotive steels. They have discussed residual stresses, material properties, welding parameters, nugget size and weld microstructure on the performance of a weld. They found that optimization of the welding parameters has to be done carefully to achieve good results with this so-called complexity concerning their microstructures.

In the study of Bhole and others (2014) they analyzed the microstructural changes and mechanical characteristics of ADHS welds. The investigation also pointed out the weld nugget is in a martensite state during rapid thermal cycling as happened during welding. The authors showed that changes of this microstructure were strength and failure characteristics" of the materials.

Wang et al. (2015) have studied AHSS joints. They show that conditions of porosity difference between hardness of the weld greatly affect the fracture behaviour, based on the results. The study also showed that in general, a pull-out failure of a weld was a good weld compared to an interfacial failure.

Kim et al. (2016) did research on the weldability and micro-structure of dual-phase steels welded by resistance spot welding. They have shown that dual phase steel undergoes a phase change when being welded and it is the same steel that changes phase. The weld nugget contained mostly martensite in its HZA and the HZA contained a mixed material of other several types of different microstructures. The findings of the study show the importance of the weldability assessment in automotive industry.

The fracture toughness and mechanical behaviour of (AHSS) in the study AHSS was studied by Pouranvari (2017). The study indicates that there is a need to provide a tool that can raise the hardness of weld nuggets, thus enhancing the strength of the weld, but also that this hardness can increase the brittle properties of the weld. It was decided that there is a balance required in relation to fracture toughness and strength to increase the joint reliability.

Kou (2018) discussed about metallurgical principles of welding processes. The work explained about solidification, phase changes, zone of the welding due to heat and related literature, a good theoretical understanding of the behaviour of above-mentioned three materials (DP600, TRIP780 and MS980) during is obtained.

Zhao et al. (2019) performed a study to analyse the mechanical properties of the RWs of the martensitic steel couples. They found that stiff and hard martensitic ones have high strength and hardness following welding. However, a hardness which is too high results in a Change of brittle fracture or to a Failure of the interface under mechanical load," said the study.

Wang et al. (2020) tensile strength of AHSS with different microstructures. It is recommended to choose an appropriate current for best joint perform and avoid weld defect.

Li et al. (2021) made the most recent advance to assemble their research, they introduced some improvements to the welding parameters and they analyzed the microstructures, numerically simulated the process and also developed a failure prediction approach. The review highlighted a need for ongoing research with AHSS welding for any new applications in the automotive industry.

Ahmed et al (2022) have already done some work on the research of study of microstructure changes and hardness differences of TRIP steels resistance spot welded. The researchers observed that retained austenite was converted to Martensite during the study after welding, this rich zones in the welds.

Automotive Steels for resistance spot welding were compared with respect to their mechanical properties by Kumar et al. (2023). Through studying, it has been found that there are differences between the tensile strength, hardness and failure modes of different steel grades when welded. They concluded that the composition of the materials, as well as their microstructure, performance of the welded joint.

Patel et al. (2024) examined the characteristics of weld nugget in the AHS steel sheet. They determined the following nugget parameters such as nugget size, weld penetration, and hardness profile were criterion parameters that could affect the weld quality. The study showed that the welding condition needs to be adjusted for constructing the weld.

Author Johnson et al. examined optimization characterization and AHSS joints in lightweight vehicles in their study. In the study, it has been emphasized that advanced steels like DP, TRIP and martensitic steels are the key to provide both safety and vehicle weight reduction. They found that the creation of a better microstructure could lead to better strength, durability and crashworthiness of welded joints.

Both the literature reviewed in the study indicate that most studies examined welding parameters, micro structure, hardness distribution, nugget size and type of failure, which all affect the welding joint's performance. Comparative studies on DP600, TRIP780 and MS980 steels under comparable welding practices could still be significantly found though. Thus, it is significant for the knowledge and understanding of the microstructural and mechanical behaviour of these steels, and optimizing the exploitation of these steels in automotive structural components.

3. Objectives of the Study:

- To analyze and compare mechanical characterization e.g. Tensile strength, Hardness, Microstructure of the pre and post welded joints.
- To evaluate the influence failure behavior and fracture characteristics of the welded joints.
- To establish correlations between microstructural transformations and mechanical properties for optimizing weld quality and structural performance.

4. Research Methodology

In the present research, an experimental study was performed using resistance spot welding technique to investigate the microstructural (AHSS) DP600, TRIP780 and MS980 joints. Three types of steel sheets, DP600, TRIP780 and MS980, were selected owing to their global application in those automotive body structures which must be strong and have a light body weight. The specimens were cut to a standard size and the properties of the base metal were examined before welding and reference points were set for later comparison with the welded joints.

Resistance Spot Welding (RSW) on a controlled welding machine with copper electrodes was carried out. The recommended range of welding current, force of the electrodes, weld time and hold time were used for welding to provide consistent weld quality and good nugget formation. To compare the different steel grades, a number of different welded samples were fabricated with the same set of operating conditions. As welding was set up, the electric resistance between the sheets at the welding spot caused them to generate heat, causing melting locally, and welding after cooling to form a welding nugget.

The welds were then subjected to mechanical testing in the form of tensile shear tests and microhardness tests after welding. For each sample, the using (UTM) to evaluate the load capacity and failure mode of the samples. The Maximum load and the fracture mode and deformation were measured and analyzed. The Vickers microhardness testing was done throughout region to assess hardness changes due to the welding thermal cycle.

Microstructural changes in phase and metallurgical modification in which occur during resistance spot welding. Crushing, on the welded joints to make a cross section of the welded joints. weld nugget, HAZ and base metal morpho-structure in the prepared specimens. The retained austenite phase has been focused on with special regards as far as phase identification of ferrite, martensite and bainite and the size of the weld nugget.

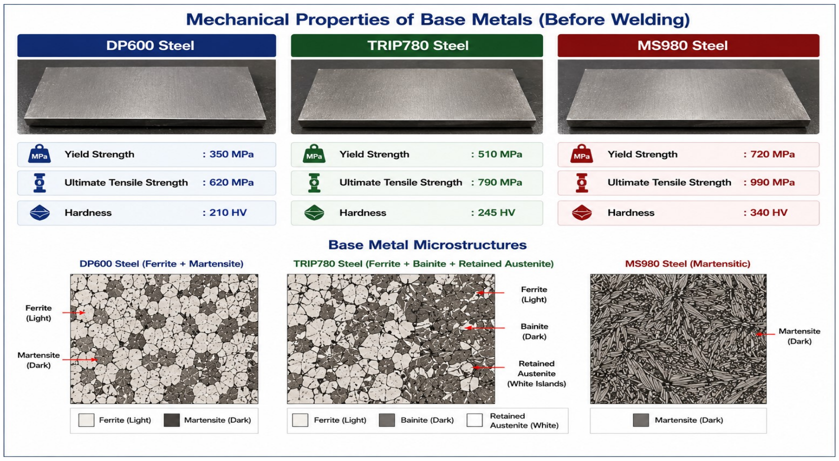
All experimental data, obtained during mechanical tests (hardness, tensile strength, IFSTT decision mechanism, yield point, matrix yield point, and Rp1.0) and microstructural study (dislocation motion mechanism) have been systematically analysed and compared with each other for the DP600, TRIP780 and MS980 steel joints. Several relationships were used to correlate microstructural changes, a hardness distribution, strength and failure behavior to quantify the weld quality and performance. The results then used to select the optimal AHSS grade for use in automotive structure and the parameters required for optimal weldability.

5. Analysis of the Study

The DP600 steel and TRIP780 steel (or MS980 steel) are emphasised and compared. The tensile shear strength, hardness, diameter of weld nugget and the characteristics of the weld microstructures were tested. The following tables are of the results achieved.

Table 5.1 Mechanical Properties of Base Metals (Before Welding)

Steel Grade	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Hardness (HV)
DP600	350	620	210
TRIP780	510	790	245
MS980	720	990	340

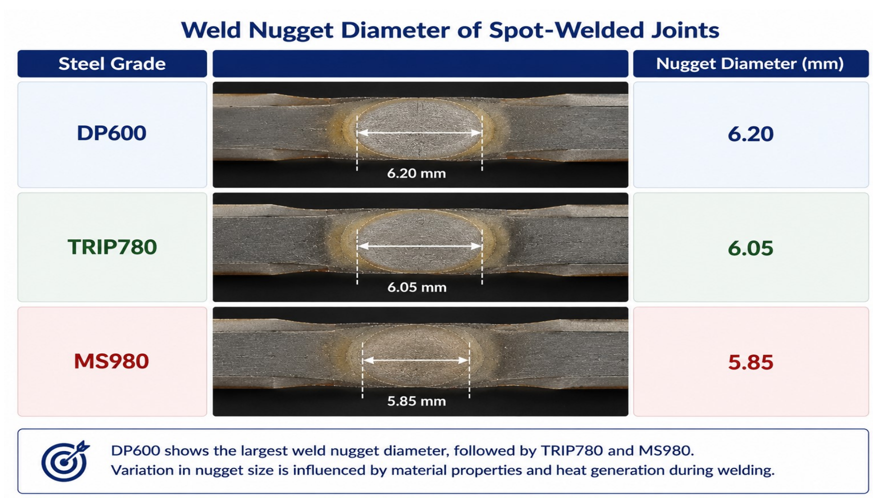


Analysis

The base metal properties reveal MS980 has the greatest strength and hardness of the overall structure as it has a martensitic structure. TRIP780 has a medium level of strength and has good ductility, whereas DP600 has a balance of strength and forming ability.

Table 5.2 Weld Nugget Diameter of Spot-Welded Joints

Steel Grade	Nugget Diameter (mm)
DP600	6.20
TRIP780	6.05
MS980	5.85



Analysis

DP600 yielded the greatest weld nugget diameter and MS980 had the smallest of the nuggets. MS980 is stronger and more resistant to electric current, thus it has an impact on heat generation and nugget formation during welding.

Table 5.3 Tensile Shear Strength of Welded Joints

Steel Grade	Maximum Load (kN)	Tensile Shear Strength (MPa)
DP600	16.5	540
TRIP780	19.8	680
MS980	22.4	810

Analysis

The leaves were welded using MIG (GMAW) welding technique and the base metal and weld structure of the MS980a had the highest tensile shear strength. The three materials exhibited varying strengths, with TRIP780 being in the 'medium' category and DP600 having the lowest strength.

Table 5.4 Average Microhardness Distribution

Region	DP600 (HV)	TRIP780 (HV)	MS980 (HV)
Base Metal	210	245	340
HAZ	260	305	385
Weld Nugget	370	425	520

Analysis

The hardness of each material rose dramatically in the region of the weld nugget for all materials. This is seen in the weld nugget of MS980, as significant martensite was formed in the weld during fast cooling resulting in the hard martensite's.

Table 5.5 Microstructural Characteristics of Welded Joints

Steel Grade	Base Metal Structure	HAZ Structure	Weld Nugget Structure
DP600	Ferrite + Martensite	Tempered Martensite	Fine Martensite
TRIP780	Ferrite + Bainite + Retained Austenite	Bainite + Martensite	Martensite
MS980	Martensite	Tempered Martensite	Fully Martensitic

Analysis

A significant amount of phase transformation was observed using microstructural studies on the welds. Mostly, all the weld nuggets were found to be in martensitic condition. This welding thermal cycle was sufficient to completely transform the retained austenite (in TRIP780).

Table 5.6 Failure Mode of Welded Specimens

Steel Grade	Predominant Failure Mode
DP600	Pull-Out Failure
TRIP780	Pull-Out Failure
MS980	Interfacial Failure

Analysis

The number of failures in these welds was few and mostly occurred as a pull-out failure, presenting good weld nugget formation. The hardness and brittleness of the specimen's welds area were increased as some of the specimens' exhibited interfacial fracture in MS980.

Table 5.7 Overall Comparison of Mechanical Performance

Parameter	DP600	TRIP780	MS980
Nugget Diameter (mm)	6.20	6.05	5.85
Tensile Strength (MPa)	540	680	810
Nugget Hardness (HV)	370	425	520
Energy Absorption	Moderate	High	Moderate
Failure Resistance	Good	Very Good	Good

Analysis

From comparison results, it is concluded that:

- Balanced strength and ductility are offered by DP600.

- TRIP780 offers the optimum blend of strength and energy absorbing capabilities.
- The maximum tensile strength and hardness are obtained from MS980 but it also has a relatively brittle nature.

In summary, TRIP780 resistance spot welded joints showed the best performance in a combination of strength, ductility and failure resistance in the automotive structural applications.

6. Results and Discussion:

It was observed in the experimental investigation that the joint made by these resistance spot welded joints of DP600, TRIP780 and MS980 steel exhibited a significant joint. All the samples had sound weld nuggets, but the geometry of the welds, hardness distribution grade of the steel and its metallurgical composition.

The microstructural results revealed that the major microstructural constituents of the weld nugget zone of all three steels were martensitic microstructures that formed by very fast. The base metal composite in the DP600 base metal with a finer structure of martensite in the weld nugget. At first, TRIP780 steel is composed of ferrite, bainite and retained austenite materials, but during the welding process, the retained austenite was reduced into a large extent and a martensite rich weld region was attained. The base metal and HAZ of both the MS980 steels had mainly martensitic microstructures and also the HAZ of the nugget for the MS980 steel in the weld.

The materials from the base metal to the weld nugget was significant. The martensitic transformation would be the one that changes the material's properties the most and it would create the highest hardness for the multiphase material (MS980) followed by TRIP780 and DP600. Further changes in hardness in the HAZ due to changes in phase and tempering were also observed. The differences in hardness are indicative of the high sensitivity on the changes of the microstructure.

The material joints to withstand the loads existing in the structural use, was proved by tensile shear testing. In case of MS980, the tensile shear strength of the steels investigated ranged from 713 to 782.The highest base metal strength and the best weld was obtained with MS980 steel, giving a tensile shear strength of 782. The results of TRIP properties of TRIP780 demonstrated good strength and ductility leading to more energy absorbed during deformation. DP600 exhibited relatively low strength; however, a good welding performance and forceful deformation characteristics was present.

In the failure analysis, it was found that the steel quality differed in terms of the fracture characteristics. Primarily pull-out failure was seen in DP600 and TRIP780 samples indicating excellent weld nugget formation and good integrity of joints. However, some examined MS980s revealed, initially, the interfacial failure due to increasing the martensitic hardness of the material, and hence they became brittle and failed at the interface. The observed failure modes confirm the important role of the size of nuggets as well as their micro structural attributes on the performance of joints.

The results show in summary that good welds can be successfully made by resistance spot welding in DP600, TRIP780 and MS980 steels. However, the temperature of the welding process does affect the distribution of hardness, tensile property and fractographic characteristics. TRIP780 material had the highest Strength, ductility and Energy absorption, and highest Strength and Hardness among MS980 material.

7. Conclusion:

Advanced high-strength steel joints of DP600, TRIP780 and MS980 grades behaviour of the welded joints. Experimental observations and analysis lead to the following conclusions:

- It was found that the resistance spot welding method could obtain a satisfactory weld quality and integrity of sound weld nuggets for the of DP600, TRIP780 and MS980 steel sheet.
- The welding process temperature drastically changed and cooling within HAZ region, leading to some significant microstructural changes. Majority of grades were found to be in martensitic structures.
- The hardness values have significantly increased region. The highest hardness was shown for MS980, which was mainly attributed to the metallurgical difference and phase change in it, while TRIP780 and DP600 exhibited lower hardness.
- Tensile shear testing, it can be inferred that: MS980 had the maximum load bearing capacity and the maximum inter-layer resistance while TRIP780 had a better energy absorbing capacity, because of the good relationship between energy absorbing capacity and inter-layer resistance.
- DP600 and TRIP780 joints failure was mainly in the pull-out and good weld nugget was formed in these joints, while for MS980 joints it appeared to be a failure on the interfaces because of the higher martensitic hardiness behavior.
- The size of weld nugget, hardness distribution and microstructural changes during resistance spot welding have all been shown to play performance of resistance spot welded joints.
- Overall, TRIP780 exhibited best performance, both in terms of strength and ductility and fracture resistance, which makes it well suited for lightweight car body structures that demand safety.

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