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Welding Order and Welding Penetration Levels' Impact on Product Life Cycle For GMAW

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ABSTRACT

Gas metal arc welding is a high-speed, economical process that is also called as "metal inert gas welding" or "metal active gas welding" which are sub-types of gas metal arc welding. This method is used for production of different parts in many industries. In this paper, the focus will be on automotive applications of this process and the impact of the parameters of this production method on the durability performance of the axle component of a vehicle. Experiments have been conducted on the axles that have been produced in serial life production conditions and have been investigated under real life road load conditions to determine their performance levels. After theoretical calculations and physical tests, each measured improvement had been documented for every parameter of the welding process. All this data had been analyzed in detail and these parameters' projected impacts on the axle life cycle had been evaluated with respect to the serial life usage condition expectations.

Keywords: Axle, durability, FEA, passenger vehicle, welding penetration, arc welding

Gaz Altı Ark Kaynağı Prosesinde Kaynak Sırası ve Kaynak Penetrasyon Seviyesinin Ürün Ömrüne Etkileri

ÖZ

Gaz metal ark kaynağı, gaz altı kaynağının alt türleri olan "metal inert gaz kaynağı" veya "metal aktif gaz kaynağı" olarak da adlandırılan yüksek hızlı, ekonomik bir işlemdir. Bu yöntem birçok endüstride farklı parça üretimleri için kullanılmaktadır. Bu bildiride, ilgili sürecin otomotiv uygulamalarına ve bu üretim yönteminin parametrelerinin bir aracın aks bileşeninin dayanıklılık performansı üzerindeki etkisine odaklanıldı. Dayanım performans seviyesi değişiklikleri; seri hayat imalat koşullarında üretilen ve gerçek hayat yol yükü şartlarında test edilen akslar üzerinde tespit edildi.Teorik hesaplamalar ve fiziksel testlerden sonra, kaynak işleminin her parametresi için ölçülen her iyileştirme belgelendi. Tüm bu veriler detaylı bir şekilde analiz edildi ve bu parametrelerin aks ömrü üzerinde öngörülen etkileri, seri ömür kullanım koşulu beklentilerine göre değerlendirildi.

Anahtar Kelimeler: Dayanım, FEA, yolcu aracı, kaynak penetrasyon seviyesi, arc kaynak

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1. INTRODUCTION

The Gas Metal Arc Welding (GMAW) is a well-known welding procedure since 20th century. Due to its low cost, flexible adjustment ability, ease of use and ease of application, this process has been favored by the industry. This method of production enabled the industry to utilize steel effectively and with higher performance. Recently, robotic applications of welding have been preferred instead of manual operations especially for arc welding, e.g., the automotive industry depends, most of all, on weld robots to keep its production line always operational. For the evaluation of the environmental impacts of state-of-the-art welding technologies, Life Cycle Assessment method has been applied. This study shows the differences between the manual metal arc welding, laser arc-hybrid welding and two gas metal arc welding process performances. Results of this study have been analyzed and improvement strategies have been documented [1].

On another note, since gas metal arc welding is one of the arc fusion processes that is widely used in industry due to its high efficiency, the direct influence of the correct selection of the input parameters on the weld quality has been analyzed as well. With this analysis, it has been shown that with the control of those parameters, it is possible to reduce the amount of weld material, improve its properties and then increase the productivity of the process. The selected method of optimization for this study was Taguchi Method and the impact of the parameters has been investigated via Variance Analysis (ANOVA). This study focused the attention on the weld voltage, weld speed and weld torch angle. The influence levels of each parameter have been documented extensively by observation of the geometrical and mechanical properties, transversal tensile strength and macrography results. The selected methods were suitable to resolve this kind of problem. The experiment was efficient, and the results were good [2].

In this paper, the focus will be on automotive applications of gas metal arc welding process and the impact of the parameters of this production method on the durability performance of the axle component of a vehicle.

Experiments have been conducted on the axles that have been produced in serial life production conditions and have been checked under real life road load conditions to determine their performance levels.

After the analysis of these tested parts, process improvement studies have been organized to achieve the desired performance levels of the durability tests of the rear axles. The adjustments that have been mentioned in this paper are directly linked to the welding parameters.

There are a lot of points that can have an impact on the durability performance, however, to be able to limit the study in a certain area, for this paper the focus is only on the two of these process parameters. The other varying factors can be checked in other studies.

2. INFORMATION ON WELDING, AXLE AND VALIDATION TEST

2.1 Welding

2.1.1 Arc Welding

Arc welding is a method to merge workpiece metals with a consumable which is generated by electric power.

Gas Metal Arc Welding (GMAW) is also called MAG/MIG. Metal Active Gas (MAG): It is a welding process with welding wire under an active gas protection (pure CO^2 or Argon/CO^2 or Argon /CO^2/Oxygen mixture), generally used for welding mild steel.

This welding process can be automatic or semi-automatic in which an electric arc is created between the consumable wire electrode and the metals that heats the parts and causes them to melt and join. [3]

General scheme of the CW – GMAW process can be seen in Figure 1 [4].

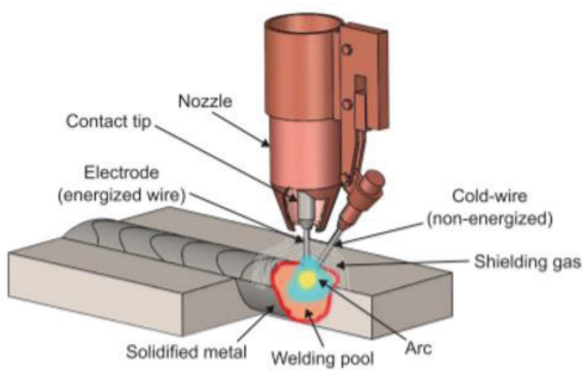

Figure 1. General Scheme of the CW - GMAW Process [4]

Metal Inert Gas (MIG): It is a welding process with welding wire under an inert gas protection (pure Ar or Argon/Helium mixture), generally used for welding aluminum alloys thus are out of this paper's scope.

2.1.2 Parameters of arc Welding

Arc welding process has too many input parameters including voltage, current, travel speed of torch, welding wire diameter and angle, wire feeding speed, welding gas, etc.

All these parameters have different effects on the welding performance. The impacts of these parameters on the welding bead performance are observed on the final products with different methods.

One of the methods to check the conformity of welding is to have a macro analysis on the welded section. In this analysis, it is possible to determine the penetration level of the welding on each component, to check the height of the welding, along with the shape-smoothness of the welding bead. It is also possible to observe the gap between the two components [5].

The second method to check the conformity of the welding is to have physical durability performance test of the final product.

For the component, rear axle, that has been analyzed for this paper, periodical visual controls of the welding beads, macro cuts, synthetic durability tests have been performed to make sure that the performance is at the expected level.

2.1.2.1 Welding Parameters

Welding parameters impact welding bead quality which has a direct correlation with durability performance of the component. In this paper the focus is on the variation between results when welding parameters and welding beam characteristics are changed.

2.1.2.2 Part Features

Required part features are decided at the beginning of the project and being verified with calculations. These features can be categorized as the material(s), thickness of the parts, type of joints, welding position, manufacturing tolerances, dispersions to be "absorbed", gaps between the parts, dispersion on joint position, surface conditions (cleaning), etc.

All these features are checked at the beginning of the physical tests. In case of any nonconform results during physical tests, first supposition is these features are correct and conform.

2.1.2.3 Main Welding Parameters

These parameters directly come from welding process and effect welding beam quality.

Parameters are decided at the prototype production stage and will be verified with several controls such as visual control, macro cut, bead length controls and if all the results of these were acceptable, lastly durability test.

These parameters can be categorized as consumables (welding wire, gas), power source parameters (wire speed, voltage...), robot trajectory (travel speed, position of the arc impact, torch angles, etc.), which can be seen in Figure 2 [6]. Welding sequence is another parameter that cannot be shown in a diagram; however, that needs to be mentioned since it will be one of the parameters that will be focused on in this paper along with welding penetration level.

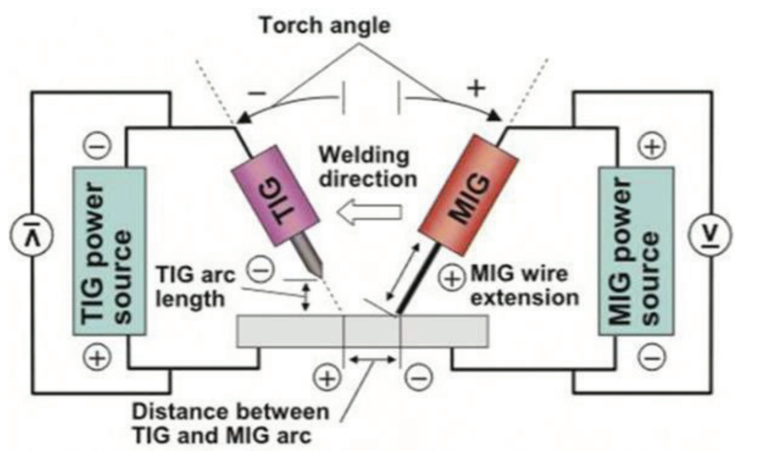

Figure 2. Schematic Model TIG – MIG/ MAG Welding [6]

2.1.2.4 Principles of Welding Sequence Determination

Welding sequence to ensure that the parts are joined properly and in line with the performance requirements of the final part is determined at the beginning of the project based on the stress calculations. Aim is to maintain stable connection between the parts throughout axle's life cycle.

During the welding process, the parts to be joined are heated locally up to the melting temperature of the material. However, the cooling process is slow compared to the warming process. This phenomenon causes local shrinkage, residual stress formation, and distortions on the parts. Residual stress, that forms on the welded parts, causes brittle fractures [4].

The magnitude and distribution of residual stresses, general welding conditions and analysis of their effects on the axle's life cycle are kept out of scope of this paper. To avoid this brittle formation and distortion on the parts, the sequence of the welding beads is modified which is one of the focuses of this paper.

2.2 Rear Axle

An axle is a support system for the weight of the vehicle which is a central shaft for a rotating wheel or gear. The number of the axles in the car depends on the type of the vehicle. In this paper, the focus will be on the passenger vehicles with two axles.

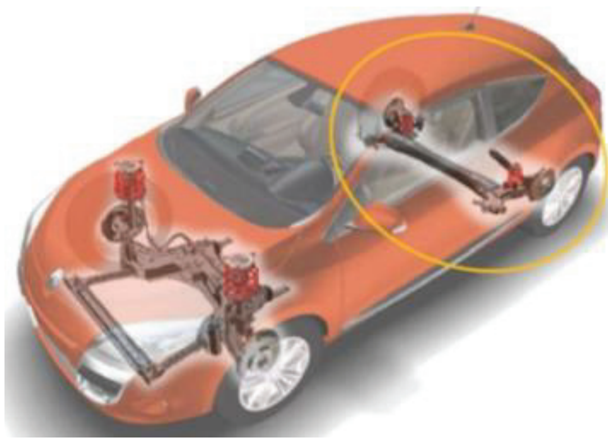

Figure 3. Schema of the Rear Axle

The axle that will be worked on is the rear axle which is highlighted in Figure 3.

The rear axles must endure the weight of the vehicle body, driving thrust, torque reaction and side thrust. To achieve this, different types of axles can be utilized. In figure 4 a sample version of typical twist beam can be seen in detail. [7].

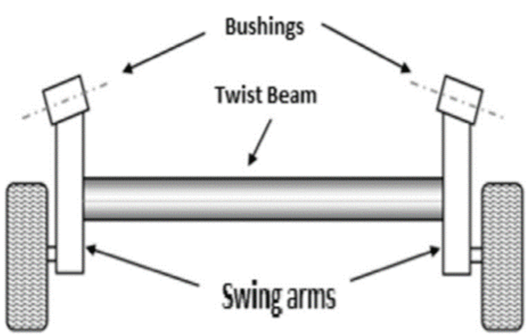

Figure 4. Example of a Typical Twist Beam Suspension [7]

The axle that will be worked on for the scope of this paper is a H shaped twist axle. There are several components that need to be joined properly to be able to provide the necessary performance for the duration of the vehicle life. The parts of the axle are joined via GMAW.

2.2.1 Components of Rear Axle

The H shaped twist beam consists of trailing arm, cross member, axle head, spring seat, anti-roll bar and couple of other supporting parts which are shown in Figure 5.

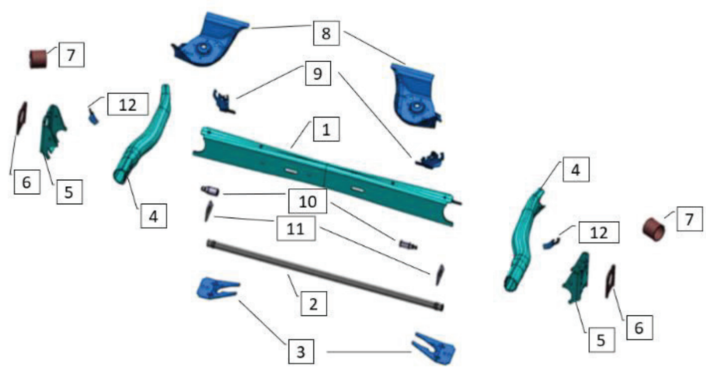

Figure 5. Components of Rear Axle (1) Cross Beam, (2) Anti-Roll Bar, (3) Gusset, (4) Arm, (5) Axle Head, (6) Support Axle Head, (7) Collar, (8) Spring Seats, (9) Supports TRF, (10) Support Choc Absorber, (11) Support Anti-Roll Bar, (12) Cable Supports.

All these components are being produced by stamping, machining, roll forming, forging, etc. The production method has been decided at the beginning of the project for each component based on the vehicle requirements along with the material grade and the thickness.

During the project development phase, the performance of each component is being checked and necessary alterations are being implemented. It is important to have a correlation between the physical test result and calculations. Other than the conformity of the components another key factor to be able to reach the desired correlation is welding operation. Based on this information, performance improvement of the rear axle can be achieved.

2.2.2 Rear Axle Welding Criteria

The welding beams are classified into classes regarding applied forces to beams and product characteristics hierarchy. These classes are defined according to customer risk analyses and to the level of stress. Each class corresponds a monitoring plan and appropriate welding criteria. Product characteristics hierarchy determines the consequence of failure for the customer. The level of stress determines the degree of risk of the failure occurring. The constraints are evaluated by simulation computation and validated by mechanical tests. [3]

2.2.3 Welding Criticity For Rear Axle

A certain durability performance level will be set up for the rear axle depending on the conditions that the vehicle will be used under. Sample graph that shows the differences of the criticity level of the welding beam can be seen in Figure 6. Based on this level, the criticity of the welding beads will be determined considering customer impact.

For the security impacts, immobilization and the non-conformities that will disturb customer without any life-threatening risks.

The performance of the welding beads will be checked throughout the life cycle of the vehicle with periodical controls.

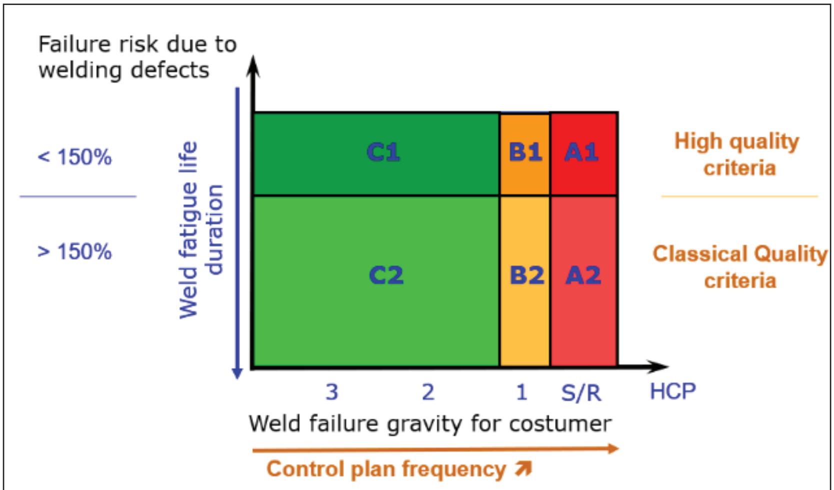

Figure 6. Welding Criticity According to Renault Welding Standard

2.3 Validation Tests

The purpose of durability test is to evaluate the durability behavior of an axle on a certified test facility by introducing synthetic stresses through the intermediary of false wheels. Equipment of the test bench for durability performance can be seen in Figure 7.

The test equipment simulates all the forces that the axle will be subjected to in real life usage on vehicles in rapid form. The signals are collected via test vehicles prior to the construction of the test sequence. These signals are stored and updated periodically. Each type of road condition has a different type of test signal sequence. The movements of the rear axle have also different type of signal sequences.

All these conditions and movement requirements are simulated during the test in x, y and z directions to ensure the relation of the test to the real-life situations. The testing program that is being used at the validation level of the axle is repeatedly modified and corrected version of the initial form with the support of the crosschecks are performed during the development phases of the axle. Simulations, 6-axis tests, and con-

Figure 7. Durability Performance Test Bench With Automatic Control For Rear Axles

centrated version of fatigue tests are continuously and closely monitored to find the right correlation and to make sure all these tests represent the real usage conditions.

2.3.1 Expected Performance Of The Rear Axle

Axles require high level of capacity for endurance and fatigue because of the twisting & untwisting during driving. At the beginning of the design period the collected signals from the real users are transformed into theoretical loads on rear axle to determine the expected performance. These expectations consist of durability, acoustic, vibrations, hardness, corrosion, drivability, handling, etc. For this paper the focus will be on the durability performance of the rear axle.

The durability performance needs to cover the complete vehicle life cycle for the conditions of the worst driver possible. The theoretical loads, which have been calculated from the road signals, are turned into bench test input. Once the rear axle is welded it needs to be durable enough to pass the bench test with expected performance.

The test is carried out on a fitted axle (with wheel assembly, joints, bearings, etc.), fixed to a rigid frame by train / body fixing points representative of the vehicle configuration. The stresses are introduced using independent and synchronized actuators. The stresses are introduced at the dummy wheel. Suspension parts (springs, shock absorbers, stops, buffers), the rubber joints, are therefore not validated during this test but remain under surveillance in the event of an anomaly (breakage or premature wear).

This durability performance test allows the damage seen on the axle during its serial life cycle usage to be reproduced in an accelerated manner where the progress of the deformations can be monitored closely. Only the welding beads' forms and the axle components' performances are followed and documented during this test, not the environmental components such as bushings, springs, etc.

2.3.2 Fatigue Failure - Durability

Durability: Ability of an item to perform a required function under conditions usage and maintenance data, until a limiting state is reached.

Reliability: Ability of an item to perform a required function, under conditions data usage, during a given time interval.

Failure Mode: How a system may stop to perform its functions. Failure mode expressed in physical terms (rupture, fatigue, jamming, leakage, short circuit) chemical or other, which resulted in failure. For different usage periods there are several failure levels of gravity.

2.3.3 Fatigue Mechanism

Welding beads are natural sites for cracks to appear. In this paper the focus will be on the welding beads of rear axle.

The welding beads create a fragile area on the parts. Thus, it is important to make sure that the welding beads are conform. The beginning and end sections especially form high stress concentration. The cracks can appear around these regions during the durability performance tests of rear axles. In this paper, the performance of welding beads which are located around the trailing arm and head axles will be inspected.

3. EXPERIMENTAL STUDIES

To ensure the durability performance of the rear axle, it is mandatory to complete a set of physical tests with components that have been produced in serial conditions. For these series of tests, the components' conformity levels should be documented in detail (geometry, material, etc.) After making sure that the components are conform, the rear axle can be welded.

The welded axle should be controlled for the geometrical conformity as a follow up step. If the position cotes of the complete axle are within the tolerance limits, next step is to check the conformity of the welding beads. For this check there are two steps: 1. visual control 2. macro cuts. Once these results are documented, it is possible to test a rear axle from the same production batch (preferably n+1 / n-1, n=macro cut part)

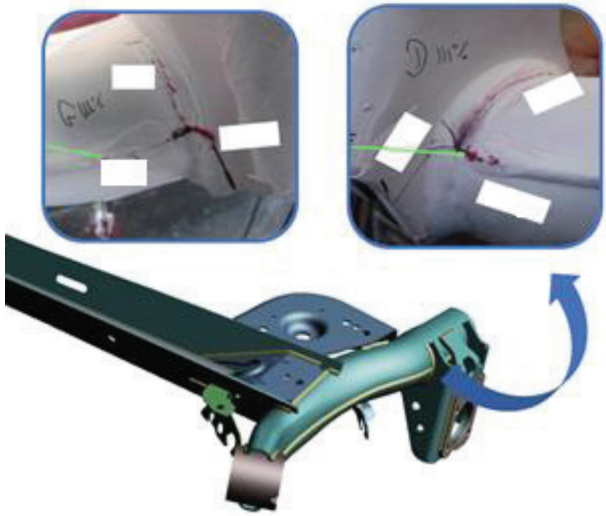

Figure 8. Welding Failure on the Arm

on durability test bench where n is the part that is destroyed for macro cut procedure thus is no longer valid for physical test, n-1 and n+1 are the before and after parts of it.

The durability test benches simulate the road and driving conditions and their impact on the axles. The signals are gathered and designed specifically for each project. During and after each test, every single welding bead will be closely examined for cracks & failures. Some of the failure examples can be seen in Figure 8.

If it is necessary, improvement studies will be performed to make sure that the axles are respecting the desired durability level. There are two specific levels for the durability tests: first one is the crack appearance and the second one is the loss of function. To be able to successfully complete the test and respect the conditions of the validation requirements, it is mandatory to pass both levels with acceptable results.

For this paper, the focus will be on the final series of physical tests and the improvement studies that have been performed on the axle head-trailing arm welding beads specifically.

For this vehicle, there are 3 different rear axle types. The specifications depend on several vehicle criteria (engine type, brake type, tire – wheel dimensions, etc.). For this paper, two types will be examined: light and heavy versions.

The scheduled number of tests have been listed as 8 for this rear axle. To be able to get the validation approval from the component experts, it is mandatory to pass all the tests with acceptable results for both levels.

3.1 Improvement Studies

The initial test results showed early cracks around the axle head – trailing arm welding bead.

Since the geometry of the parts have been confirmed prior to the test, the improvement studies have been focused on the welding parameters. The first thing that have been checked was the penetration levels of the welding beads.

To make sure that the levels are at the desired level, the depth of the penetration has been checked with 5mm intervals on the welding bead after the test failed. It was visible that the middle section of the welding beam did not fit the criteria. The macro cut results of the n-1 & n+1 rear axle showed close to the limit values for those regions as well. Thus, the first action of improvement was decided as increasing the penetration of the welding bead in the middle section for the axle head – trailing arm assembly. The activity has been organized as an additional welding bead on top of the current route. After the completion of the welding beads in serial life production conditions, the macro cuts of the same region have been compared. The results showed major improvement for the welding penetration level in the middle section of the welding bead.

In parallel, the stress levels of the same region have been checked. There are four different welding beads in a very small region which will create extra stress for that area. In Figure 9, the welding bead positions can be seen for arm, axle head and collar section of the rear axle.

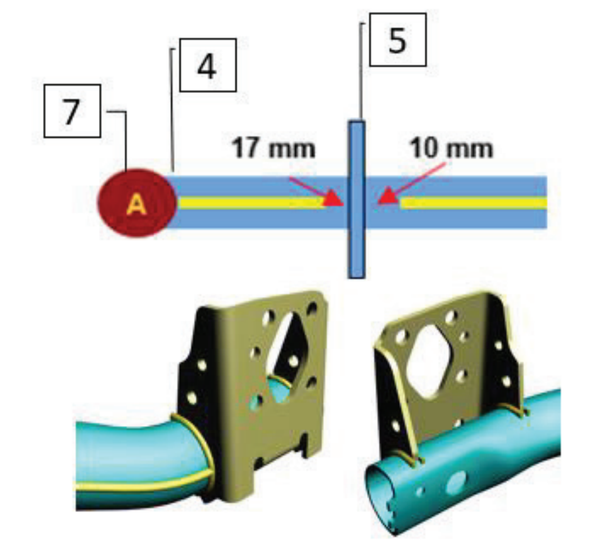

Figure 9. (4) Arm, (5) Axle Head, (7) Collar

It is known that high stress can cause cracks under additional loads. Thus, the sequence of the welding beads has been recorded for this additional welding beads.

After the trial of the second sample, the attempt was once more failure. However, the cracks appeared at a much later period, yet again felt short of the desired level. To be able to continue with the improvements of the welding performance, the welding beads sequence has been changed to make sure that additional stress for the afore mentioned region will not be created. Also, the beginning and ending portions of the welding beads have been analyzed to see the penetration level and the bonding of the components. The results were at the acceptable level for this aspect. Thus, the positioning of each component on the welding jig was also conform just as the geometry of each component. Because of this conformity, the stress levels have been checked one more time. To eliminate the extra stress, it was decided to leave certain gaps between each welding bead's beginning and ending points (gap: distance between welding beads). The ability of this application depends solely on the equipment that is being used in the welding cell along with the welding fixture's movement capacity. For these rear axle components, the gaps have been defined in simulation studies after the completion of the prior etudes.

Then the decided values have been applied on the third rear axle with the addition of the initial improvement studies. With all these activities in line, it was possible to pass the initial crack limit with flying colors and focus on the loss of function level.

For the second and final level of the validation test, it was necessary to pass the defined limit of the bench with all functions of axle intact which means no fractured components and no separated-cracked welding beads. To be able to determine what needs to be done at which level on which component or welding bead, the tested parts are being checked within short periods with visual equipment & chemicals which allow the cracks & fractures to become visible for the test operator. The duration of this test has been set as 2 complete weeks for this axle. The checks have been performed every 4 hours by the test operator. After the passage of the no crack level, the axle is being watched regularly till the end of the test. For this axle, after the welding beads have been improved with the first three axles, there were no additional failures and / or faults for the remaining period. Thus, it was not necessary to perform additional analysis and etudes. The initial studies were sufficient to improve the performance of the axle and all eight tests have been completed without any problems. [3]

4. RESULTS

Each improvement action resulted with different impact level on the durability performance of the axle.

For the light version of the axle, small crack formation completely disappeared in the time it took until half of the test was finished. The cracks that have been detected at the beginning of the study around trailing arm and axle head welding beads shrunk down to half of their initially measured sizes. Other cracks that have located around traverse completely disappeared till the end of the durability test.

As for the heavy version of the rear axle, the crack ap-pearances around traverse region have been successfully eliminated completely till the end of the test. For the function loss level criteria that has been set for the durability checks, desired level has been achieved and more than 70% of the tests that have been performed passed beyond the target levels.

5. CONCLUSIONS

In serial life production of this vehicle, the macro cuts and the durability tests of this axle are being checked with regular intervals. In case of non-conformities, the improvement studies will be implemented immediately, and the parts will be blocked till the confirmed solution is in place.

For the axle that has been mentioned in this paper, it was not necessary to continue with the improvement studies once the results showed confirm values with respect to the expectations. The performance of the axle has been improved via the adjustments of the welding parameters and the sequence of the welding beads. This approach enabled achieving the desired results faster in comparison to the component design modifications which require tool, mold, equipment modifications. This additional activity would have taken extra time to complete and would have created extra cost for the project. The process adjustments were fast, cheap, and sufficient to reach the targets. All the variables that are related to the welding parameters had been evaluated separately and the outcomes of each adjustment had been documented, then followed closely. This methodology showed the required performance levels can be achieved without the design changes of the components up to certain levels.

Thus, unless there is a change with the material and / geometry of the components of the axle, or any other modification during the production steps, equipment, parameters, or on the environmental components of the axle, or expectations of the axle – vehicle performance, etc. there will be no need for adjustments and additional calculations, etudes. The approved version will have the necessary performance level throughout the vehicle life.

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