FATIGUE CHARACTERIZATION OF AUTOMOTIVE STEEL SHEETS

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ABSTRACT

The aim of this study is to evaluate the fatigue behaviour, after different welding processes, of innovative steels in comparison with common low carbon steels.
The types of steels analysed are: FeP05, DP600 (Dual Phase), and TRIP800.
The types of welding analyzed are: spot-welding, arc welding, MIG brazing and laser welding.
The final result is an increased knowledge of the fatigue behaviour of each type of steel, before and after welding.
Furthermore for each class of steels its behaviour after welding (for all the welding processes mentioned above) and the reasons of a possible decrease of mechanical characteristics are evaluated.

INTRODUCTION

In the last decade the problem of light-weighting vehicles has become more and more important. In the future, because of stricter environmental rules, this aspect will be more significant.
Consequently the automotive industry is force to introduce more extensively lighter materials, but always in a cost control perspective.
Therefore the materials that can be employed are essentially Aluminum and Magnesium for castings and more sophisticated steel sheets.
The introduction of High Strength Steels and Ultra High Strength Steels involved new aspects to evaluate because of different microstructures and chemical analysis, and of course different mechanical characteristics.
One of the most important aspects to consider is the weldability of these steels and their behaviour after welding. These are important information for the designers, in order to let them design the components of the appropriate materials with the correct mechanical characteristics.

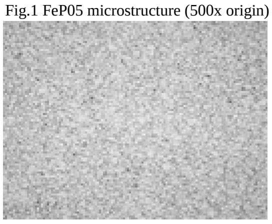
EXPERIMENTAL

Steels

The types of steels analyzed in this study cover the actual range of materials used nowadays in the automotive industry.
FeP05 represents the traditional class of material used until now, DP600 is one of the first introductions of steels with different phases in order to improve the mechanical characteristics, Trip800 represents one of the last evolution towards more sophisticated and complex materials.
Because of corrosion resistance, all the steel sheets used in the automotive industry are galvanized (electro-galvanized or hot-deep galvanized); so all the material tested is galvanized, with a Zn layer of 7-10 μm of thickness.

FeP05

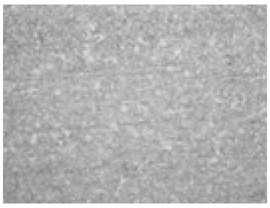
Fig.1 FeP05 microstructure (500x origin)



Traditional steels designed for deep and extra-deep drawing applications.
Unalloyed mild steels with microstructure consisting of a nearly pure ferrite matrix, fig.1.
Low carbon non alloyed steels; mechanical characteristics increase only due to work hardening effect during drawing operation.
Equi-axial grain distribution due to annealing treatment after rolling.
Extremely used in automotive industry, both for appearance-sensitive parts and structural components.

DP600

Fig.2 DP600 microstructure (500x origin)



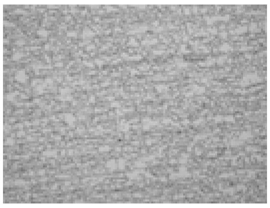
Microstructure consisting of a fine dispersion of hard martensite particles in a pure ferrite matrix, fig.2.

The combination of high strength (martensite) and ductility (ferrite), and the capacity for strain hardening lead to good fatigue properties and good energy absorption characteristics, making these steels suitable for structural and reinforcement components.

The range of Dual Phase steels goes from 450 MPa up to 1400 MPa of Ultimate Tensile Strength. The chemical composition doesn't change a lot; UTS increase is due essentially to different continuous annealings.

TRIP800

Fig.3 Trip800 microstructure (500x origin)



Microstructure composed of ductile ferrite matrix containing small islands of hard bainite and retained austenite, fig.3. Transformation of retained austenite to martensite during deformation causes significant strain hardening and retards the onset of necking. Efficient strain redistribution during forming (hence good drawability) combined with high yield strength and energy absorption in the finished component, make these steels suitable for structural and reinforcement parts.

<u>Types of welding</u>

Spot welding

It's the most common welding process used in automotive industry; more than 85% of the joinings are spot-welded.

Tests conducted with a low frequency welding machine, 6 mm diameter copper electrodes.

Welding times and currents used: same as production.

Arc welding

MAG welding, with conventional filler material (mild steel, C = 0.06.0.11%, Mn=1.4-1,6%, Si = 0.9-1.1%) of 1mm diameter, with gas shield (80%Ar, 20% CO_2).

Welding machine: same robot used in production.

MIG brazing

Welding process where the filler material is not melted with the base material; usually employed due to its low heat input (compared to arc welding). Conventional filler material (Cu=97% and Si=3%) of 1mm diameter and a 100% inert atmosphere (Argon) have been adopted.

Welding machine: same robot used in production.

Laser welding

Tests conducted with a CO_2 – 3.5KW laser source. Welding speed: 2 m/min. Three different types of laser line have been analyzed; circular, cross-sectional, and oblique.

TESTS

Fatigue

The aim of this examination was to investigate the effects of each type of welding on the steel microstructure, particularly in the thermal affected area. Therefore only one single test piece was welded (no overlapping or butt-welding of two pieces), in order to consider only the effects caused on the material microstructure (no geometrical influences are interested). The usual traction test piece was used (dimensions are in fig.4).
In this study the basic fatigue limit (not welded condition) of all materials is compared to the steel fatigue limits for each welding processes analyzed.

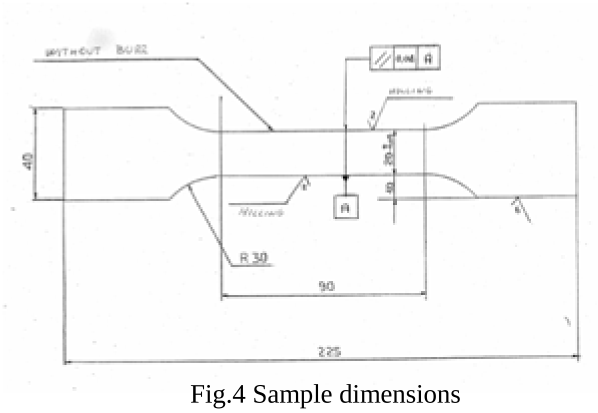


Fig.4 Sample dimensions

Tests conducted by means of an electromechanical high frequency vibrophore, using both continuous and dynamic stresses.
Traction-pulsating type has been chosen as fatigue test, with a R= $\sigma_{min}/\sigma_{max}$ ratio of 0.05. Consequently the test piece was always under a traction stress.
As usual for steel sheets, 2 millions life cycles were assumed as infinitive life.

Fatigue limit was statistically determined according to Stair Case Method.
A scale of maximum stress or half amplitude cycle was initially defined, separated by a fixed gap. We started with a stress value assumed close to the fatigue limit. If the test piece completed the whole test (2 millions cycles), next test was conducted with the upper stress value of the pre-set scale. On the other hand if the test piece didn’t reach 2 millions cycles, next test was conducted at the lower stress value of the pre-set scale.
In order to achieve a reliable statistical base, at least 18-20 tests were conducted for each analysis.
Fatigue limit was determined correlating the fatigue tests failures (and non failures) with the respective stress values.
This method brought to a fatigue limit probability of 50%.
Dispersion, if necessary, could also be determined, and could bring to fatigue limit probabilities of 10% or 90%.

Micrographic and Fractographic analysis

For each type of steel characterized, we did a specific study considering all the welding processes mentioned before.
Specifically, for each type of welding process we conducted the following evaluations:
- Micrographic analysis in order to examine the different microstructures of the welded area and the thermal affected area
- Hardness measurements (Vickers) in order to verify the thermal effect that each welding has on the steel structure
- Visual evaluation of all the broken test pieces in order to find and study all the different types of fractures
- SEM fractographic exam in order to find out types and causes of fractures

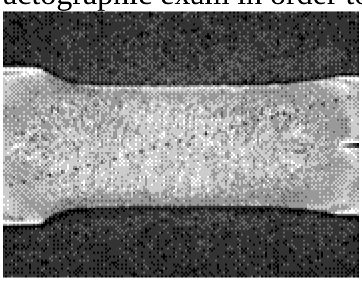


Fig.5 Spot welding +Vickers hardness of Trip steel

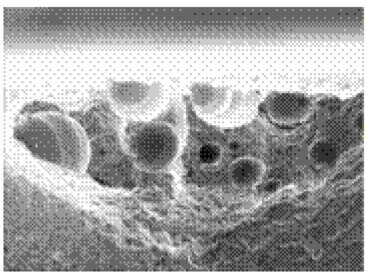


Fig.6 SEM picture of Trip steel laser welded

RESULTS AND DISCUSSION

Table I shows the welding processes analyzed; arrows orientation indicates the decreasing of the fatigue limit found for each welding process.

FeP05
Laser (transverse)
Laser (diagonal)
MAG welding
Laser (circular)
Spot welding
MIG Brazing

DP600
MIG Brazing
Spot welding
Laser (diagonal)
Laser (transverse)
Laser (circular)

Trip800
MAG Welding
Spot Welding
MIG Brazing
Laser (transverse)

Table I: fatigue behaviour of the welded steels

The FeP05, DP600 and Trip800 steels Wohler curves after the different welding processes are reported in figs.7.

- Trip800. The greatest fatigue limit decrease has been found for Trip 800 steel, because the residual austenite of the base material is transformed in martensite during the welding process and consequently the structure becomes more brittle.

Among Trip 800, MAG arc welding has the best behaviour; the fracture always occurs along the welding bead.

Spot welding has a bigger fatigue limit decrease probably because the electrode indentation concentrate the stresses in that area.

MIG brazing shows bigger fatigue limit decreases because of the presence of a silicon enriched layer (in the area between bead and heat affected zone) that has a brittle effect; furthermore there's always a sharp edge at the edge bead that has a geometrical notch effect.

Laser welding has the worst fatigue behaviour. This because Trip 800 is an alloyed high strength steel and consequently very susceptible to every thermal cycle that occurs in the thermal affected area. Vickers hardness confirms this theory; values up to 500 HV were measured.

Therefore Trip 800 is a steel with very high mechanical properties, that with the actual welding equipments requires an accurate welding process.

- DP600. Also DP600 shows a greater fatigue limit decrease in comparison with FeP05 steel. This because of a more complex microstructure; FeP05 microstructure is essentially composed by ferrite, while DP600 has a ferrite matrix with some martensite.

Microanalysis showed that biphasic structure is very susceptible to every heat input because during the phases transformations residual stresses are produced inside martensite areas.

For MIG brazing the fatigue limit decrease is because of the notch effect generated by the welding bead that prevents the material transformation in the thermal affected area, but mostly creates a fracture initiation (as for Trip 800).

DP600 laser welding presents great fatigue limit decreases because its ferritic-martensitic microstructure is very susceptible to heat production during welding process. On the contrary FeP05 steel laser welding has a good fatigue behaviour because its ferritic matrix is not susceptible to heat production during the welding process.

Spot welding fatigue test shows same results for FeP05 and DP600 steels.

Generally fatigue tests have confirmed criticalities of laser welded galvanized sheets because at high welding temperatures Zn vaporizes and, because of high solidification speeds, is kept inward the melted material causing porosity.

Tables II show the different hardness for each steel and welding process.
For FeP05 and DP600 steels hardness is not related to welding processes.

	FeP05
Melted material	200 HV1
Thermal Affected Area	190 HV1
Base material	90 HV1

	DP600
Melted material	400 HV1
Thermal Affected Area	240 HV1
Base material	200 HV1

Trip800	MAG	Spot weld.	MIG Braz.	Laser (transv.)
Melted material	435 HV1	492 HV1	--	480 HV1
Thermal Affected Area	350 HV1	320 HV1	422 HV1	360 HV1
Base material	240 HV1	240 HV1	240 HV1	240 HV1

Tables II: hardness values for different zones in the welded steels

Finally static tensile tests has been done; Ultimate Tensile Strength [MPa] and Enlongements are shown for the steels analyzed in table III.

TYPE OF WELDING	TRIP 800			DP 600			FeP 05	
	UTS	Enl.%		UTS	Enl.%		UTS	Enl.%
NOT WELDED	808	29		616	24		288	43
MAG WELDING	832	22		--	--		--	--
SPOT WELDING	824	28		--	--		298	41
MIG BRAZING	--	--		620	23		288	35
LASER (TRANVERSE)	693	10		622	20		283	35
LASER (CIRCULAR)	--	--		624	23		289	41
LASER (DIAGONAL)	--	--		621	15		318	38

Table III: Ultimate Tensile Strength [MPa] and Enlongements of the welded steels

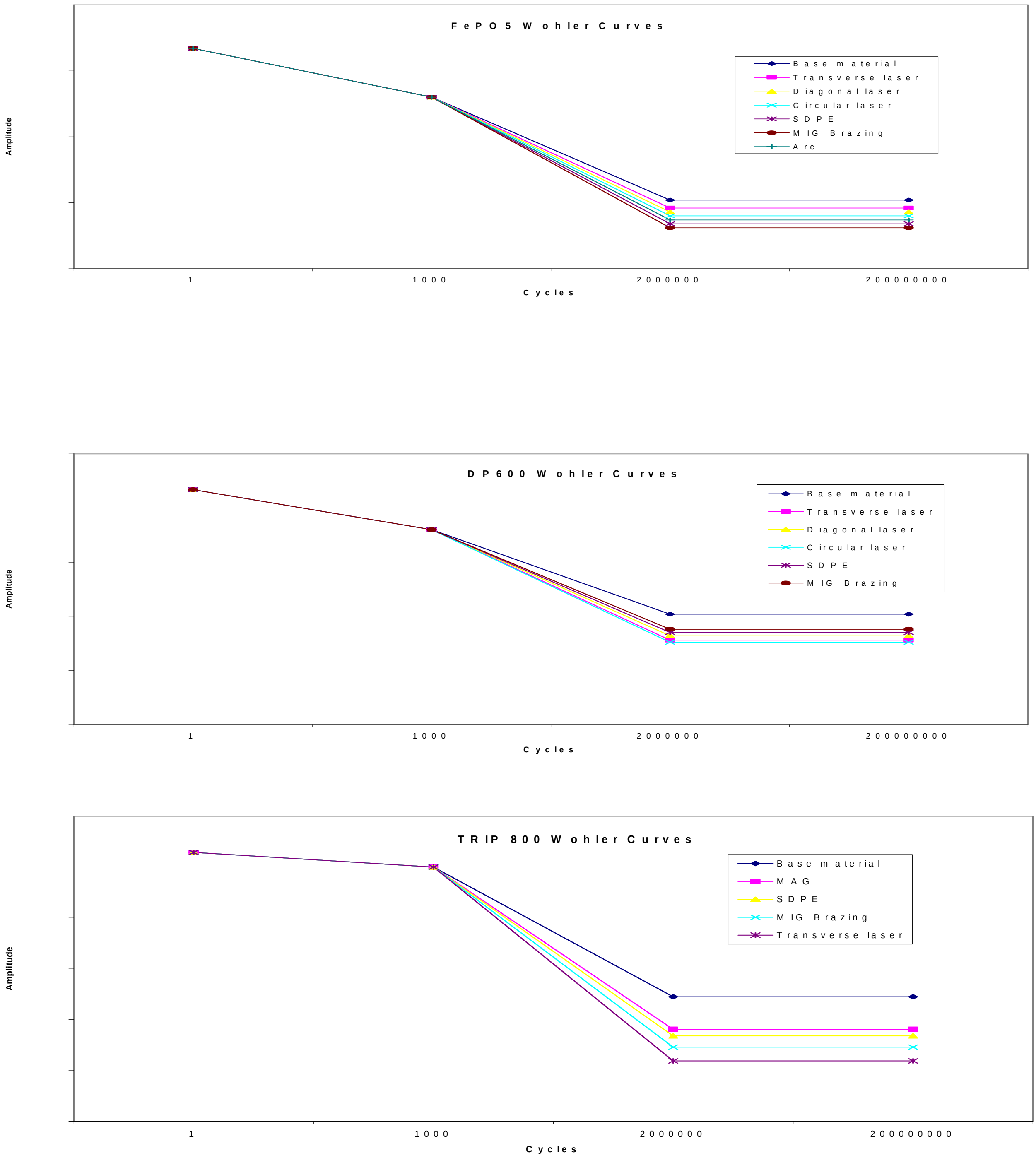
CONCLUSION

The fatigue behaviour, after different welding processes (spot welding, arc welding, MIG brazing and laser welding) of DP600-Dual Phase and Trip800 innovative steels in comparison with FeP05 common low carbon steels has been evaluated.

The greatest fatigue limit decrease has been found for Trip800 steel, because the residual austenite of the base material is transformed in martensite during the welding process and consequently the structure becomes more brittle. Therefore Trip8000 is a steel with very high mechanical properties, that with the actual welding equipments requires an accurate welding process.

Also DP600 shows a greater fatigue limit decrease in comparison with FeP05 steel, because its ferritic- martensitic microstructure is very susceptible to heat production during welding process.

Furthermore fatigue tests have confirmed criticalities of laser welded galvanized sheets because at high welding temperatures Zn vaporizes and, because of high solidification speeds, is kept inward the melted material causing porosity.



Figs. 7 Wohler curves of FePO5, DP600 and TRIP 800 steels after different welding conditions

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