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Application of Ultrasonic Peening for Fatigue Life Improvement of Automotive Welded Wheels

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ABSTRACT

The efficiency of Ultrasonic Peening (UP) application for fatigue life improvement of automotive welded wheels was studied based on the results of fatigue testing of real wheels in as-welded condition and after application of the UP. During the fatigue loading, the cracks initiate in the weld toe zone at the start and the end areas of the welds. Firstly, the fatigue cracks are observed on the surface and, with the increase in the number of loading cycles, the cracks propagate through the thickness of the material in the rim area causing at certain stage the air leakage. The improvement treatment of welded wheels was performed using the Computerized Complex for UP. On average, the speed of UP of weld toe was about 0.5 m/min. The crack propagation rate in welded wheel subjected to UP was significantly lower than the fatigue crack propagation rate in the wheel in as-welded condition. The comparison of the fatigue life, using the same crack length criterion, had shown that the UP treated welded wheels demonstrated three times longer fatigue life that the same automotive wheel in as-welded condition.

KEYWORDS: Ultrasonic peening, automotive welded wheel, fatigue life improvement

1. Introduction

The Ultrasonic Peening (UP) is a relatively new and promising technology for fatigue life improvement of parts and welded elements [1-5]. The UP technology was a logical continuation of the work done before and directed at investigation and further development of known techniques for surface plastic deformation such as shot peening, hammer peening and needle peening [6]. During the different stages of its development the UP process was also known as ultrasonic treatment (UT) [7-10], ultrasonic impact technique/technology/treatment (UIT) [11-13], ultrasonic impact peening (UIP) [14-17].

The UP technique is based on the combined effect of the high frequency impacts of the special strikers and ultrasonic oscillations in treated material. A number of research projects were completed to optimize the UP process and to find the efficiency of UP for different applications such as the increase in fatigue life of welded elements, elimination of distortions caused by welding and other technological processes, relieve of residual stresses, increasing of material's hardness. The results of fatigue testing showed that UP is the most efficient technique for increasing the fatigue life of welded elements as compared to such existing improvement treatments as grinding, TIG-dressing, shot peening, hammer peening, etc.

Among the advantages of UP one can mention the following:
- High (highest) efficiency
- Quick (treatment speed of ~ 0.5 m of weld/min)
- Considerably reduced vibrations and noise levels, easier in use than for example hammer peening
- Deeper penetration
- Computer controllable
- Robotic line - ready
- Lighter with no need in forced water-cooling as compared with similar magnetostrictive systems.

The computerized complex for UP of materials, parts and welded elements was developed recently based on high efficiency optimized piezoelectric transducers. The complex consists of a compact ultrasonic transducer, a generator and a laptop with expert system for UP optimum application (Fig. 1).

The UP system (total weight - 5 kg) includes:

1. The hand tool that is based on a piezoelectric transducer. Weight of the tool is ~3 kg and it is convenient for use. A number of working head types were designed for different industrial applications.
2. An ultrasonic generator with low power consumption. The weight of the generator is ~ 2 kg. The output frequency is ~ 22 kHz.
3. A laptop containing a software package (optional item) for Optimum Application of UP designed for maximum possible increase in fatigue life of welded elements with minimum cost, time and power consumption. The software was developed based on original predictive model.

Figure 1. Computerized complex for Ultrasonic Peening of parts and welded elements

The efficiency of UP application for fatigue life improvement of automotive welded wheels was studied based on the results of fatigue testing of real wheels in as-welded condition and after application of the UP. The results of fatigue testing of welded wheels are presented and discussed in this document.

2. Ultrasonic Peening and Fatigue Testing of Welded Wheels

2.1. Description of the Welded Wheel

The general view of welded wheel, which was subjected to UP, is presented on Figure 2.

Figure 2. The general view of the automotive welded wheel used in the project

The rim and the disc of the wheel are made of different materials with the following mechanical properties:

Rim: tensile strength - 610MPa, yield strength - 510Mpa,
Disc: tensile strength - 610MPa, yield strength - 400MPa.

The weld that connects the rim and the disc of the wheel is intermittent, not continuous. There are five 100 mm welds in the wheel. The general view of one of the welds in as-welded condition is presented in Figure 3.

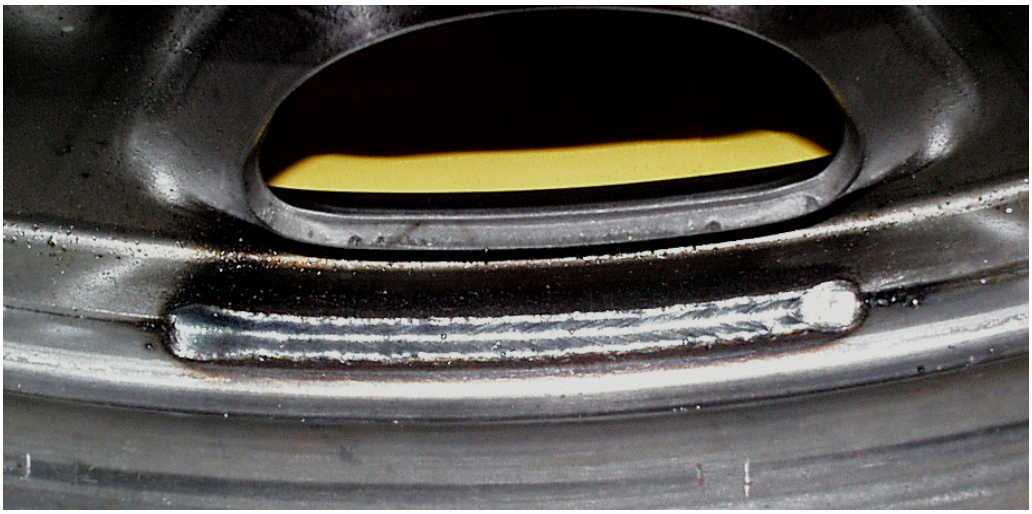

Figure 3. General view of the weld in as-welded condition

Technology of Welding: Gas shield welding (MAG).

2.2. Origination and Propagation of Fatigue Cracks in Welded Wheel in As-Welded Condition

Parameters of cyclic loading:

Test method - rolling test simulating of the straight driving under severe radial load,
The stress amplitude near the weld end ~ 80MPa,

The schematic diagram of the fatigue loading of automotive welded wheel is presented in Fig. 4.

The testing had shown that the fatigue life of the wheel in as-welded condition is less than 1 million cycles. During the fatigue loading, the cracks initiate in the weld toe zone at the start and end area of the weld (Figure 5). The fatigue cracks are observed, firstly, on the surface and, with the increase in the number of loading cycles the cracks propagate through the thickness of the rim causing air leakage to occur. The fatigue life of this type of welded wheel is determined by the fatigue life of start and end areas of the welds.

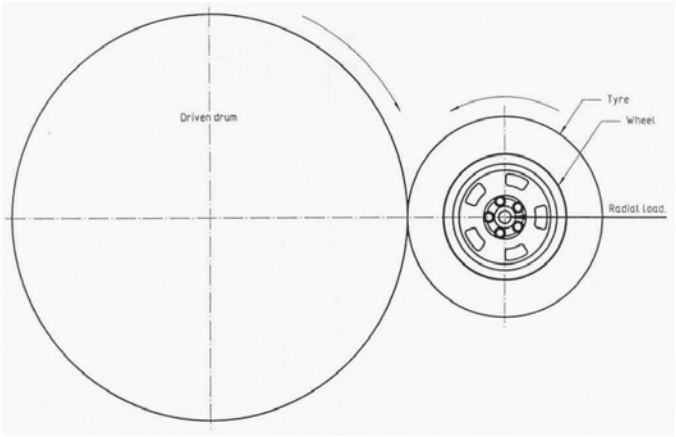

Figure 4. The schematic diagram of fatigue loading of the automotive welded wheel

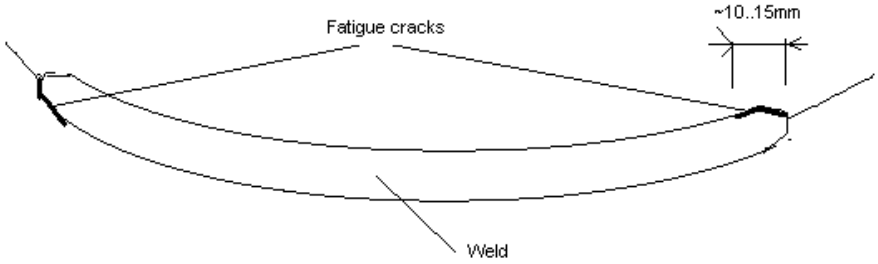

Figure 5. Schematic view of the weld with fatigue cracks

2.3. Ultrasonic Peening of Welded Wheels

The UP of welded wheels was performed using the computerized complex for Ultrasonic Peening (see Fig. 1). The average speed of UP treatment of the weld toe was about 0.5 m/min. In the used in this project welded wheels there were regions with difficult access using the standard UP equipment. In this case more time totally was spent for UP treatment then calculated time. Customized equipment, in such cases, could resolve the problem with the speed of UP treatment for complex and difficult to access geometry of parts and welded elements.

The most critical from the fatigue point of view zones were UP treated in all wheels, i.e. the start and the end areas of all welds, as well as the length of weld toe from the rim side. The general view of the weld after UP treatment is presented in Figure 6.

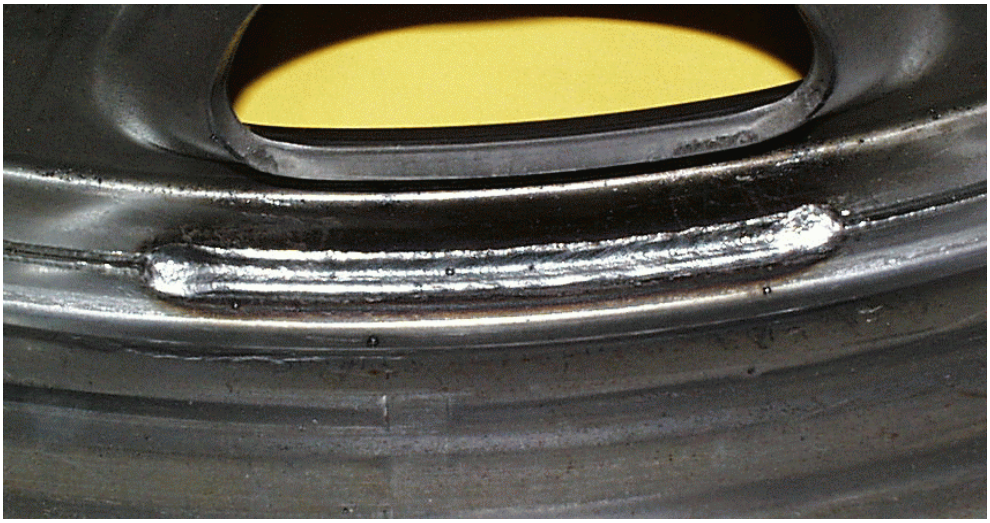

Figure 6. General view of the weld after Ultrasonic Peening

2.4. Fatigue Testing of Welded Wheels after Ultrasonic Peening

It was established that crack propagation rates in the welded wheels subjected to UP treatment are significantly lower than the fatigue crack propagation rates in wheels in as-welded condition. The comparison of the fatigue life by the criterion of the same crack length shows that the UP treated welded wheels have more than three times longer fatigue life that the same wheels in as-welded condition. The results of fatigue testing of welded wheels showing the dynamic of the origination and propagation of fatigue cracks in as-welded condition and after UP are presented in Table 1.

Table 1. Data illustrating the origination and propagation of fatigue cracks in welded wheels in as-welded condition and after UP treatment

			Crack length (mm)									
No.	Condition	Number of	Weld 1		Weld 2		Weld 3		Weld 4		Weld 5	
of the wheel	of the wheel	cycles	Start	End	Start	End	Start	End	Start	End	Start	End
1	**As-Welded**	1.00E+06	10	3		3	10	3	10	5		5
2	**After UP**	1.00E+06			1	1			1			
		1.50E+06			1	1	2	6	1	2		
		2.50E+06			1	1	2	6	2	3		
		3.00E+06			2	5	5	6	2	3		
		4.00E+06		1	2	15	13	7	7	3	12	
3	**After UP**	1.00E+06			1	2		2				
		1.50E+06			4	6	1	4				
		2.50E+06			15	6	2	8		1	1	

3. Discussion

A number of R&D and industrial projects directed at optimization of the UP process and at determination of the fatigue strength of UP treated welded elements were completed in the past. Mainly, “standard” welded elements listed in national and international codes on fatigue design of welded elements and structures were considered in these studies. The results of the fatigue testing had shown that UP is the most effective and economic way to improve the fatigue strength of welded elements.

In case of UP treatment application to increase the fatigue life of the considered welded wheels a few factors that could affect the result should be mentioned:

1. Difficult access with existing standard UP equipment to some to be treated zones, especially the weld toe of beads from the disc side. A solution to this problem would lie in using customized equipment.

2. “Poor” fatigue design of welded elements - the presence of an “artificial crack” between the rim and disk in the zone of weld.

3. “Poor” quality of welding.

If welded elements with enhanced fatigue performance are required, the following stages should be considered together: “good” fatigue design, welding of high quality and, finally, the UP treatment. If the design of the welded wheel is predetermined by other factors, there is still a good potential in improving the quality of welding of the wheels. The UP helps, in addition, to reveal the presence of possible defects in the welds. The crack-like defects became visible on the UP treated surface. There is also a good potential in the selecting of welding parameters to increase the fusion zone between the disc and the rim, at the same length of welds, to reduce the level of nominal stresses in weld during cyclic loading.

4. Conclusion

1. The efficiency of Ultrasonic Peening (UP) application for fatigue life improvement of automotive welded wheels was studied based on the results of fatigue testing of real wheels in as-welded condition and after application of the UP.

2. The crack propagation rates in the welded wheels subjected to UP treatment were significantly lower than the fatigue crack propagation rates in wheel in as-welded condition. The comparison of the fatigue life by the criterion of the same crack length showed that the UP treated welded wheel has three times longer fatigue life that the same wheel in as-welded condition.

5. References

1. Y. Kudryavtsev, J. Kleiman, L. Lobanov, V. Knysh and G. Prokopenko. Fatigue Life Improvement of Welded Elements by Ultrasonic Peening. *International Institute of Welding. IIW Document XIII-2010-04. 2004. 20 p.*

2. Y. Kudryavtsev, J. Kleiman, G. Prokopenko , V. Trufiakov and P Mikheev. Ultrasonic Peening of Weldments: Experimental Studies and Computation. *IX International Congress on Experimental Mechanics. Orlando. Florida. USA, June 5-8, 2000. p. 504-507.*

3. Y. Kudryavtsev, J. Kleiman, G. Prokopenko, P. Mikheev and V. Knysh. Mechanism and Efficiency of Ultrasonic Peening in Fatigue Improvement. *SEM Annual Conference & Exposition on Experimental and Applied Mechanics. Milwaukee, Wisconsin, USA, June 10-12, 2002. (on CD)*

4. Y. Kudryavtsev, J. Kleiman, G. Prokopenko, B. Mordyuk, T. Krasovskiy P. Mikheev and V. Knysh. Computerized Complex for Ultrasonic Peening of Parts and Welded Elements. *32-nd Annual Ultrasonic Industry Association Symposium. New York, NY, USA, October 21-23, 2002. (on CD)*

5. Y. Kudryavtsev, J. Kleiman, G. Prokopenko, V. Knysh and L. Gimbrede. Effect of Ultrasonic Peening on Microhardness and Residual Stress in Materials and Welded Elements. *SEM International Congress and Exposition on Experimental and Applied Mechanics. Costa Mesa, California, USA, June 7-10, 2004. (on CD)*

6. V. Trufyakov, P. Mikheev and Y. Kudryavtsev. Fatigue Strength of Welded Structures. Residual Stresses and Improvement Treatments. *London. Harwood Academic Publishers GmbH. 1995. 100 p.*

7. I. Polozky, A. Nedoseka, G. Prokopenko et al. Relieving of welding residual stresses by ultrasonic treatment. *The Paton Welding Journal. 1974. No. 5. p. 74-75.* (in Russian)

8. V. Krivko and G. Prokopenko. Ultrasonic treatment of welded joints. *Welding Production. 1979. No. 5. p. 32-33.* (in Russian)

9. A. Gruzd, A. Kazimirov, A. Nedoseka and G. Prokopenko. Influence of ultrasonic treatment on texture and properties of AMг6 alloy. *Paton Welding Journal. 1980. No. 7. p. 38-41.*

10. P. Mikheev, A. Nedoseka, A. Parkhomenko et al. Efficiency of ultrasonic treatment application for increase of fatigue strength of welded joints. *Paton Welding Journal. 1984, No. 3. p. 4-7.*

11. Y. Kudryavtsev, V. Korshun and A. Kuzmenko. Improvement of fatigue life of welded joints by the ultrasonic impact treatment. *Paton Welding Institute. 1989. No. 7. p. 24-28.*

12. Y. Kudryavtsev, P. Mikheev and V. Korshun. Influence of plastic deformation and residual stresses, created by ultrasonic impact treatment, on the fatigue strength of welded joints. *Paton Welding Journal. 1995. No. 12. p. 3-7.*

13. V. Trufiakov, P. Mikheev, Y. Kudryavtsev and E. Statnikov. Ultrasonic Impact Treatment of Welded Joints. *International Institute of Welding. IIW Document XIII-1609-95. 1995.*

14. V. Trufyakov, P. Mikheev, Y. Kudryavtsev and D. Reznik. Ultrasonic Impact Peening Treatment of Welds and Its Effect on Fatigue Resistance in Air and Seawater. *Proceedings of the Offshore Technology Conference. OTC 7280. 1993. p. 183-193.*

15. V. Trufyakov, P. Mikheev, Y. Kudryavtsev and D. Reznik. Review of Fatigue Improvement Treatments and Introduction of Ultrasonic Impact Peening Treatment. *Abstracts of Papers. 74-th AWS Annual Convention. 1993.*

16. V. Trufyakov, P. Mikheev, Y. Kudryavtsev and D. Reznik. Ultrasonic Impact Peening Treatment of Welds. *ABS Fatigue Improvement Seminar. Houston, USA. 30 April, 1993. 31p.*

17. V. Trufyakov, P. Mikheev, Y. Kudryavtsev and D. Reznik. Fatigue Endurance of Welded Joints. Residual Stresses and Fatigue Improvement Treatments. *Ship Structure Symposium'93. Arlington, Virginia, USA. November 16-17, 1993. p. N1 - N14.*