

coefficient of restitution, micro-jet welding, car body parts

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## COEFFICIENT OF RESTITUTION AND PLASTIC STRAIN FOR IMPACT OF ELEMENTS WELDED WITH MICRO-JET COOLING

**Summary.** The main purpose of investigations is the qualification how post-accident repair of model car body parts influence on the value of coefficient of restitution. Evaluation of impact energy absorption by model car body parts repaired with MIG welding (with and without micro-jet cooling) was carried out. The results of investigations present that the value of coefficient of restitution changes with speed of impact. Coefficient of restitution is bigger for elements welded with micro-jet cooling than for element welded with ordinary method. This could have influence on passive safety of vehicle.

## WSPÓŁCZYNNIK RESTYTUCJI I ODKSZTAŁCENIE PLASTYCZNE PRZY UDERZENIU ELEMENTÓW SPAWANYCH Z CHŁODZENIEM MIKROJETOWYM

**Streszczenie.** Głównym celem badań jest określenie wpływu metody spawania (MIG z chłodzeniem mikrojetowym i bez chłodzenia) naprawianych części nadwozia pojazdu na wartości współczynnika restytucji i ich odkształcenie plastyczne. Wyniki z badań przedstawiają wartość współczynnika restytucji w funkcji energii uderzenia. Współczynnik restytucji jest większy dla elementów spawanych z chłodzeniem mikrojetowym niż dla elementów spawanych zwykłą metodą. To może mieć wpływ na bezpieczeństwo bierne pojazdu.

### 1. INTRODUCTION

Absorption of impact energy is very important during car crash. The way of absorption influences on value and time course of deceleration. Deceleration appears during car crash and depends on velocity of car in moment of crash, time course of crash and construction of vehicle. Very important is construction of vehicle. Carbody should have properly values of plastic properties. It has a positive effect on the reduction of deceleration value. Improve of plastic properties could be reached with welding with micro-jet cooling [1÷5].

Coefficient of restitution  $R$  describes the way of impact energy absorption and describes what part of impact energy is recovered in second part of impact, when vehicle reflects from barrier. Moreover, coefficient of restitution describes what part of impact energy is use up to plastic strain and elastic strain. For entirely plastic impact  $R = 1$ , but for entirely elastic impact  $R = 0$ . In reality impacts have elastic-plastic character and  $0 < R < 1$  [6].

For collisions of cars to fixed barrier with the relative velocities bigger than 20 km/h the coefficient of restitution is smaller than 0.1. When the velocity is smaller coefficient of restitution is in range from 0.2 to 0.6 and is marked by big scatter. These values are experimental effects for vehicle like vans and pickups. Fig. 1 shows coefficient of restitution it depends on impact velocity for vans and pickups [7].

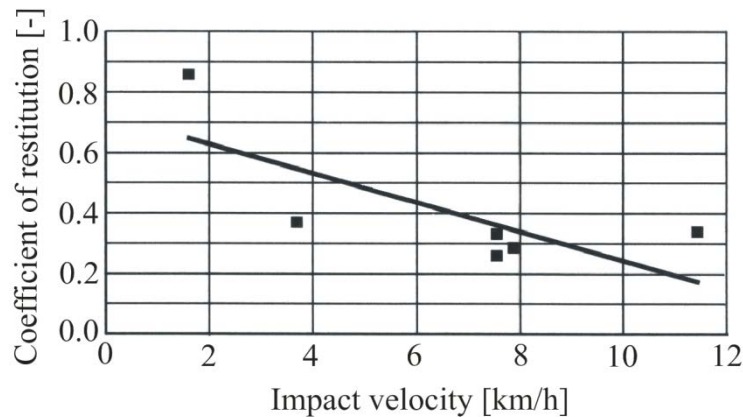


Fig. 1. Value of restitution coefficient depending on impact velocity

Rys. 1. Wartość współczynnika restytucji w zależności od prędkości przy uderzeniu w przeszkodę

In case of steel plastic properties of welds are very important. The high content of acicular ferrite (AF) is a guarantee of high plastic properties. Proper values of these parameters are required for safety maintenance of welded construction. Example of that construction can be carbody after post-accident repair with welding method.

New micro-jet cooling technology could be regarded as a new way to obtain the effect of structure steering during welding. In the steel structure the best plastic properties of weld correspond with maximal amount of AF in weld metal deposit (WMD). High amount of AF in WMD has influence on plastic properties of welds.

## 2. RESEARCH

Coefficient of restitution can be calculated by using a lot of methods. Usually it is hard to do and research results have a big distribution. One of the way is method in which are registered two height and two mass during free fall (formula 1).

$$\lim_{M \rightarrow \infty} R = \lim_{M \rightarrow \infty} \frac{1}{M} + \frac{1+M}{M} \sqrt{\frac{h_2}{h_1}} = \sqrt{\frac{h_2}{h_1}} \quad (1)$$

where:  $m_1$  – mass of pendulum [kg],  $m_2$  – mass of sample + mass of test stand + foundation [kg],  
 $h_1$  – height of pendulum drop [m],  $h_2$  – height of pendulum reflect [m]

Before investigation three very important things should have been selected. There are test stand, samples and impact conditions.

The investigations have been carried out on single-blow impact testing machine, which is described in standard [8]. The test stand had proper attachment to the foundation. Form of pendulum was modified. Moreover, course of the tests did not comply with the standards, because samples were not cracked into two parts and pendulum after impact returned (fig. 2).

Mass of test stand was about 700 kg and the mass of pendulum was 20 kg. Test stand has been fixed to the foundation ( $m_2 \rightarrow \infty$ ). During investigation two height have been registered: height of pendulum drop ( $h_1$ ) and height of pendulum reflect ( $h_2$ ).

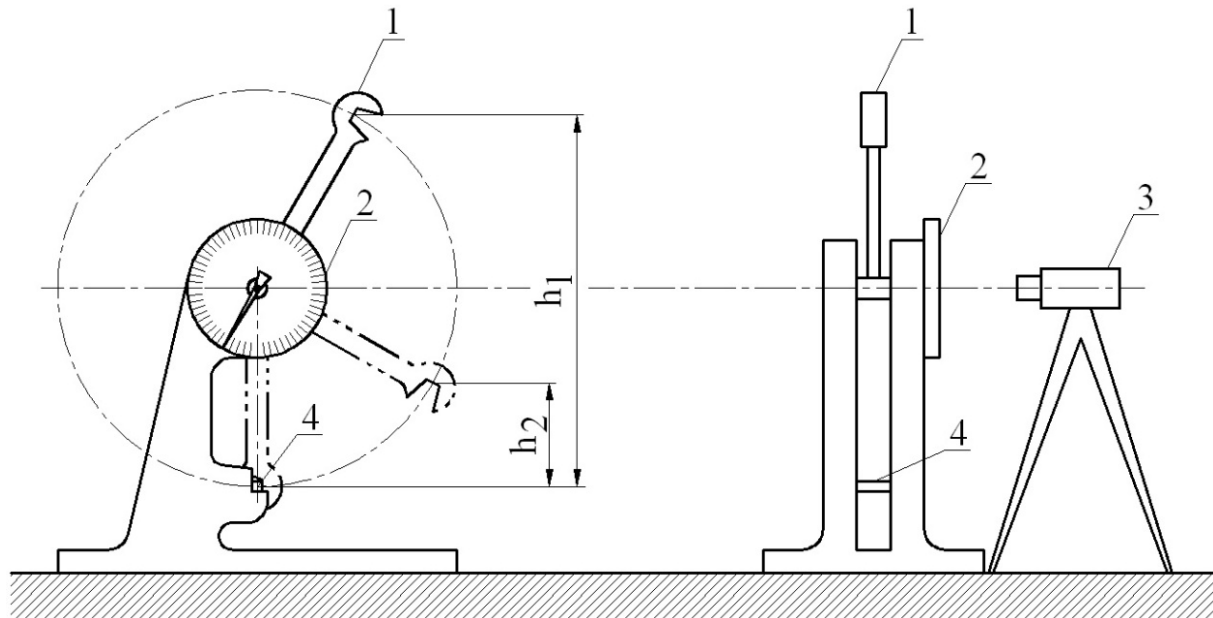


Fig. 2. Test stand: 1 – pendulum, 2 and 3 – registration device, 4 – sample  
Rys. 2. Stanowisko badawcze: 1 – wahadło, 2 i 3 – układ rejestrujący, 4 – próbka

The samples have been made with S235 steel. Chemical constitution and mechanical properties of this steel have been shown in table 1 and table 2.

Table 1  
Chemical constitution of steel used in investigation [9]

No.	Chemical element	Content, %
1.	C	0.17
2.	S	0.035
3.	P	0.035
4.	Si	0.10 ÷ 0.35
5.	Mn	1.40
6.	Cu	0.55
7.	Ni	0.12

Table 2  
Mechanical properties of steel used in investigation [9]

No.	Property	Value
1.	Yield stress, MPa	235
2.	Tensile strength, MPa	380 ÷ 520
3.	Elongation $A_{50}$ , %	16

Three kinds of samples were made for investigation:

- samples without weld,
- samples welded with MIG method without micro-jet cooling,
- samples welded with MIG method with micro-jet cooling.

Fig. 3 shows welded samples used in investigations. Table 3 presents parameters of welding process.

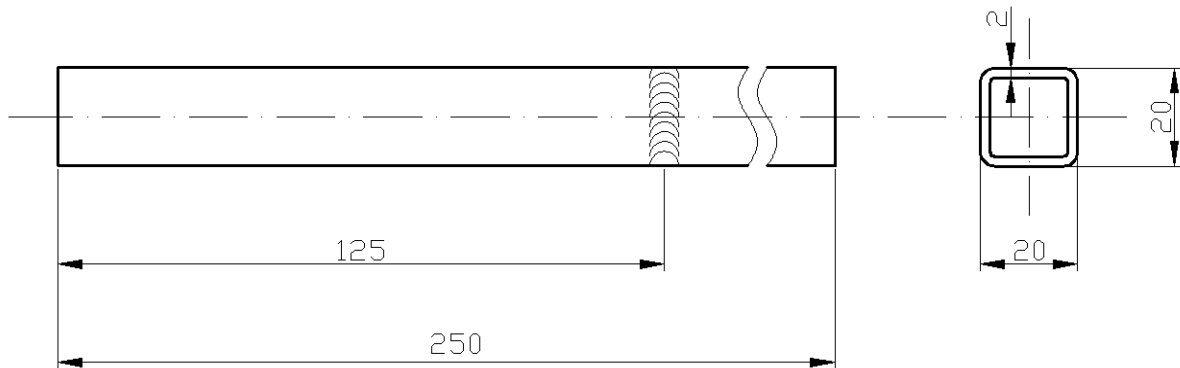


Fig. 3. Sample with weld

Rys. 3. Próbkę do badań ze spoiną

Table 3

Parameters of welding process

No.	Parameter	Value
1.	Diameter of wire	1.2 mm
2.	Standard current	220 A
3.	Voltage	24 V
4.	Shielding welding gas	Ar
5.	Micro-jet cooling gas	Ar
6.	Gas pressure	0.4 MPa

During test pendulum has been drop from height  $h_1$ . Pendulum has hit on sample. Sample has been deformed depending on impact energy. Next pendulum has reflected and returned to height  $h_2$ . In table 4 have been shown value of impact energy and velocity of pendulum during investigation. Fig. 4 shows the way to plastic strain measurement.

Table 4

Impact conditions during investigations

No.	Height of pendulum drop ( $h_1$ ), m	Impact energy, J	Impact velocity, m/s, (km/h)
1.	1.61	315.9	5.6 (20.2)
2.	1.56	306.1	5.5 (19.9)
3.	1.41	276.6	5.3 (18.9)
4.	1.22	239.4	4.9 (17.6)
5.	0.91	178.5	4.2 (15.2)

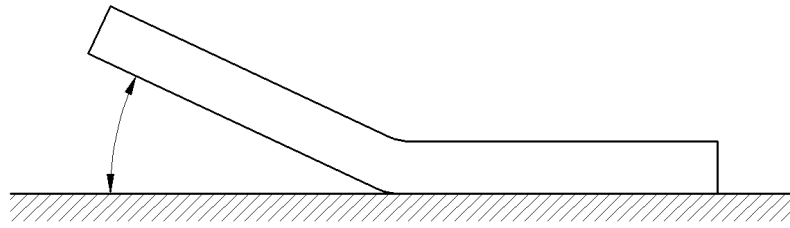


Fig. 4. The way of plastic deformation measurement  
Rys. 4. Sposób pomiaru odkształcenia plastycznego

### 3. RESULTS

This work introduced value of coefficient of restitution for post-accident model carbody parts. The investigations have been carried out with five level impact energy/velocity.

Fig. 5 shows plastic strain depending on impact energy for three kinds of samples. Plastic strain increased when impact energy increased. This situation was independent of the kinds of samples. Model samples without weld have the smallest plastic strain. The biggest plastic strain has been reached for samples welded with ordinary MIG method without micro-jet cooling. Using of micro-jet welding positively influences on plastic strain. Plastic strain was smaller than for samples welded with ordinary MIG method. This situation was observed for each value of the impact energy.

Fig. 6 shows value of restitution coefficient depending on impact energy for three kinds of samples. Value of restitution coefficient decreased when impact energy increased. Generally, samples without weld had biggest values of restitution coefficient. The smallest value of restitution coefficient has been reached for samples welded without micro-jet cooling. In this case using of micro-jet cooling during welding influenced positively on obtained values.

For impact energy about 178.5 J and 239.4 J results were very similar for all kind of samples. For impacts with energy 276.6 J, 306.1 J and 315.9 J cracks were observed for samples welded without micro-jet cooling. Cracks always were observed in heat affected zone. There were no cracks in the weld in any case. For samples without weld and for samples welded with micro-jet cooling cracks were not observed. Example of samples after impact are shown in fig. 7.

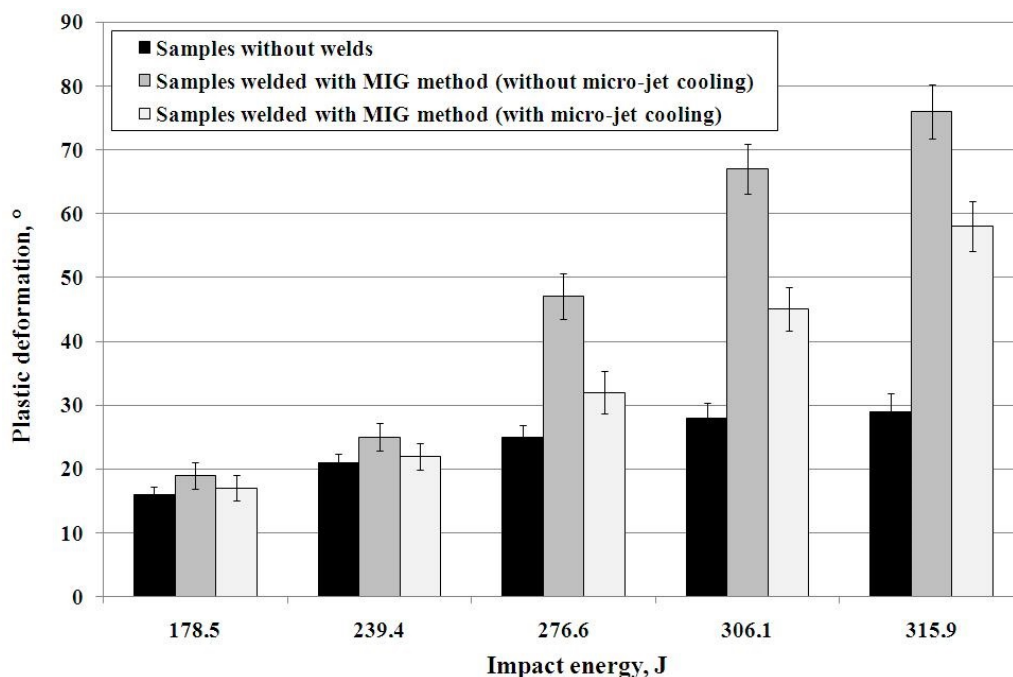


Fig. 5. Plastic deformation of samples after impact  
Rys. 5. Odkształcenie plastyczne próbek po badaniach

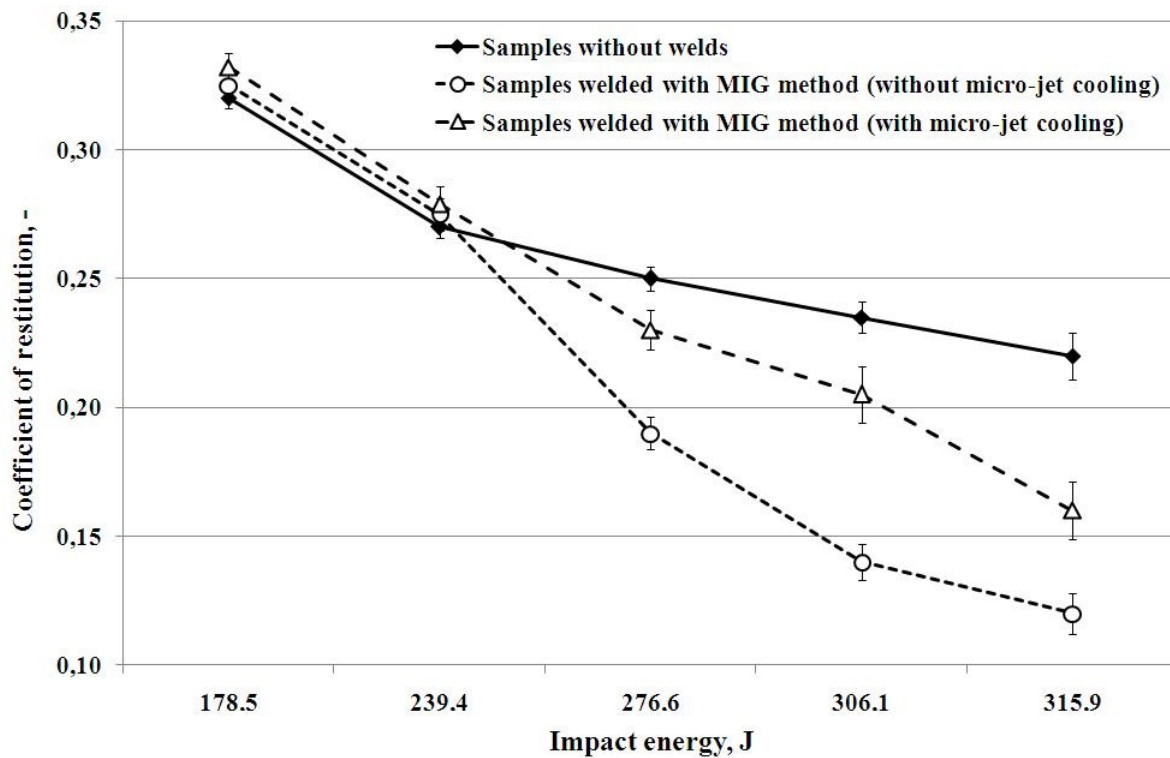


Fig. 6. Coefficient of restitution depending on impact energy for samples with and without weld  
 Rys. 6. Współczynnik restytucji w zależności od energii uderzenia dla próbek bez spoiny i ze spoiną

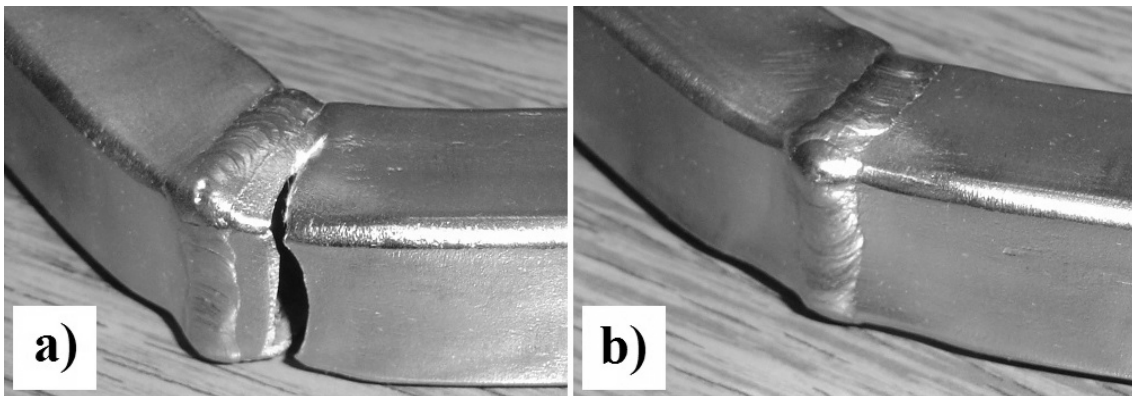


Fig. 7. Example of samples after impact: a) sample welded with micro-jet cooling, b) sample welded without micro-jet cooling  
 Rys. 7. Przykładowe próbki po uderzeniu: a) próbka spawana bez chłodzenia mikrojetowego, b) próbka spawana z chłodzeniem mikrojetowym

#### 4. SUMMARY AND CONCLUSIONS

The results of investigation shows that post-accident repair of car body parts influences on value of coefficient of restitution and in a result on level of passive safety of post-accident vehicle.

Plastic strain increases with improving the impact energy for all kinds of samples. The biggest plastic strain was observed for samples welded without micro-jet welding. Using of micro-jet cooling for welding process influences on plastic strain. Samples welded with micro-jet cooling achieved smaller values of plastic strain than samples welded with ordinary MIG method.

Value of restitution coefficient decreases with improving the impact energy for all kinds of samples. For small impact energy (178.5 J and 239.4 J) results were very similar. For bigger impact energy (276.6 J, 306.1 J and 315.9 J) results were different for all kinds of samples. The biggest values of restitution coefficient were observed for samples without welds. The smallest values of restitution coefficient were observed for samples welded with ordinary MIG method. Using of micro-jet cooling for welding process influences on coefficient of restitution. Samples welded with micro-jet cooling achieved bigger values of restitution coefficient than samples welded with ordinary MIG method.

In all cases using of micro-jet cooling technology for welding influenced positively on obtained results. This situation can be explain by the following way. Micro-jet cooling in welding process allows to obtain effect of weld structure steering. In this way structure of weld metal deposit could be steered. It allows to obtain the most beneficial phase – acicular ferrite (AF). This phase is responsible for the high plastic properties of the weld [4, 10]. Further research on welding with micro-jet cooling are conducted. Their results are promising.

On the basis of investigation it is possible to deduct that:

- micro-jet-cooling could be treated as an important element of MIG welding process,
- using welding with micro-jet cooling allow to achieve better results of restitution coefficient than for case without micro-jet cooling,
- using welding with micro-jet cooling allow to achieve better results of plastic properties than for case without micro-jet cooling,
- welding with micro-jet cooling can be use for post-accident repair of carbody elements.

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