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THE INFLUENCE OF THE LASER AND DIFFUSION BORONIZING ON THE SURFACE LAYER OF NODULAR IRON

Summary

Cast irons are commonly used in case of many machine parts in different industry branches, also in agricultural industry. A lot of such machine parts are exposed to tribological wear and corrosion. Therefore, surface layers with improved properties are needed. This paper refers to two different ways of modification of the surface layer of nodular iron. The aim of this research was to compare the effects of the laser boronizing and diffusion boronizing of nodular iron, especially the influence of boron concentration on the hardness of modified surface layer. An optical and scanning electron microscopes, Auger electron spectroscope (AES) and hardness Vickers tester were used to assess the results of the surface layer treatments. The performed research showed, that after diffusion, as well as, after laser boronizing of nodular iron higher hardness of the surface layer (in comparison to the core material) was obtained. Coarse-grained, needle-like shape of iron borides with ferrite grains after diffusive boronizing and very fine-crystalline, homogenous microstructure after laser alloying were observed. Hardness changes measurement from the surface on the cross-section for both cast irons treated with those methods of boronizing were correlated with the registered changes of boron concentration. Nevertheless, this correlation was stronger for diffusion boronizing than for laser modification. Smaller correlation for the zone achieved after laser boronizing is possibly a result of other aspects which influences the hardness and are characteristic for laser treatment like creation of very fine grains or supersaturated solid solutions (unlike diffusion treatment). It was stated, that it is possible to use less alloying element in case of laser treatment to achieve similar hardness to the surface layer after diffusion modification. Higher microstructure fineness and homogeneity, gentle hardness changes on the cross section of the surface layer form the surface to the core material after laser boronizing (in comparison to diffusion boronizing) should favor the wear resistance of machine part as well as be conducive to the selection of this kind of treatment.

***Key words**: surface layer, boronizing, laser treatment, diffusion treatment, Auger electron spectroscopy*

WPŁYW BOROWANIA LASEROWEGO I DYFUZYJNEGO NA WARSTWĘ WIERZCHNIĄ ŻELIWA SFEROIDALNEGO

Streszczenie

Żeliwa stosowane są w przypadku wielu części maszyn w różnych gałęziach przemysłu, w tym w rolniczego. Wiele z nich jest narażonych na zużycie tribologiczne i korozję. W związku z tym potrzebne są warstwy wierzchnie o odpowiednich właściwościach. Niniejszy artykuł dotyczy dwóch metod modyfikacji warstwy wierzchniej żeliwa sferoidalnego. Celem tych badań było porównanie efektów borowania laserowego i borowania dyfuzyjnego żeliwa sferoidalnego, a w szczególności wpływu koncentracji boru na twardości wytworzonej warstwy wierzchniej. Do oceny skutków obróbki powierzchniowej został wykorzystany mikroskop optyczny i skaningowy, spektroskop elektronów Auger (AES) i twardościomierz Vickersa. Przeprowadzone badania wykazały, że po borowaniu dyfuzyjnym, jak i po laserowym żeliwa sferoidalnego uzyskano zwiększoną twardość warstwy wierzchniej (w porównaniu do materiału rdzenia). Po borowaniu dyfuzyjnym obserwowano gruboziarnistą mikrostrukturę z iglastymi borkami żelaza i ziarnami ferrytu. Natomiast mikrostruktura strefy naborowanej za pomocą laserowej obróbki cieplnej była drobnoziarnista i jednorodna. Zmiany twardości zmierzone od powierzchni na przekroju poprzecznym dla obu żeliw po obróbce tymi metodami borowania korelowały z zarejestrowanymi zmianami koncentracji boru. Z tym, że zależność była silniejsza w przypadku borowania dyfuzyjnego niż modyfikacji laserowej. Mniejsza zależność w przypadku borowania laserowego jest prawdopodobnie wynikiem innych czynników wpływających na twardość, które są charakterystyczne dla obróbki laserowej, jak powstawanie bardzo drobnych ziarn czy też silnie przesyconych roztworów stałych (w przeciwieństwie do mikrostruktury otrzymywanej w wyniku obróbki dyfuzyjnej). Stwierdzono, że aby osiągnąć podobną twardość warstwy wierzchniej w przypadku laserowej obróbki cieplnej do twardości po modyfikacji dyfuzyjnej możliwe jest stosowanie mniejszej ilości pierwiastka stopowego. Uzyskanie większej jednorodności, drobnoziarnistości mikrostruktury, łagodne zmiany twardości na przekroju warstwy wierzchniej od powierzchni w kierunku materiału rdzenia po borowaniu laserowym (w stosunku do borowania dyfuzyjnego) powinny sprzyjać większej odporności na zużycie elementów maszyn z żeliwa sferoidalnego oraz sprzyjać w wyborze właśnie tej powierzchniowej obróbki cieplnej.

***Słowa kluczowe**: warstwa wierzchnia, borowanie, obróbka laserowa, obróbka dyfuzyjna, spektroskopia elektronów Auger*

1. Introduction

The automation of agricultural production processes which includes area of agricultural production and area of designing and construction of agricultural machines is one of the most essential trends in enhancement of the agricultural technique.

Using new materials and their production methods could cause important changes in construction of machines. These methods include surface layer treatments dedicated to parts which are exposed i.e. to wear or corrosion [1].

The research presented below concerns surface treatments which could be applied in case of cast iron used in agricultural machine devices.

Gray irons are popular group of materials. One of them, nodular iron, after appropriate treatment could replace cast steel or even steel in some parts of machines. For example, 38GSA steel usually used for working in soil plough blades could be replaced by ADI cast iron [2, 3].

Some parts of agricultural machines made of cast irons like: shafts of harvest machine, gears, teeth harrows, disc harrows, coulter presser feet are exposed to intensive wear. Consequently, appropriate surface layer properties are required. Diffusion boronizing is one of the surface treatments which allow to achieve substantial changes in surface layer. The point of this kind of treatmnet is saturating the layer with boron. Such boronized layer improves properties of machine parts like: fatigue surface durability, abrasive, fretting and erosive wear resistance, corrosion and fatigue corrosive resistance, heat-proof (to 800°C in atmosphere) [4]. After diffusion boronizing both kinds of borides (FeB and Fe_2B) usually appear (FeB at surface and Fe_2B under it). Hardness of Fe_2B borides is approx. 1400-1800 μHV, while FeB is higher (1800-2400 μHV). However, FeB borides are more prone to cracking and chipping off [5]. Existence of FeB boride and needle-shaped microstructure of layer increase brittleness of the surface layer. Moreover, in case of gray irons diffusion treatment non-continuous zone of graphite can appear [6]. Diffusion processes make possible to produce modified surface layer on whole of treated machine part. However, they are time-consuming and element carrier medias used in this kind of treatment need to be utilized.

Laser heat treatment (LHT) is alternative treatment which creates hard and corrosive resistible phases formed by boron in the surface layer.

Laser modification is dynamically developing technique of improving materials surface layer microstructure and properties. Performed own research [7, 8] proved that, it is possible to implement boron into the surface layer by laser alloying and achieve its homogenous microstructure as well as improve hardness of the surface layer without needle-shaped microstructure of borides. Cast iron after laser alloying with boron is characterized by better wear resistance, as well [9]. Moreover, it is possible to control the quantity of boron in the melted zone, so FeB forming could be avoided [10]. The thickness of boronized layer could be larger than thickness obtained by diffusion boronizing. In addition, by laser boronizing a stable boron distribution in the layer could be achieved. Another advantage of laser boronizing consists in existence of the hardened area below the melted layer (because of high velocity of laser treatment process). Therefore, hardness decrease from the surface to the core material is gentle [8]. Existence of the hardened zone from the solid state below the boronized zone after laser treatment (unlike diffusion boronizing) should favor gentle changes in the internal stresses in the cross section of the surface layer of treated material, which has a great importance in case of durability and reliability of the particular machine part.

The aim of the presented research was to compare the effects of the laser boronizing and diffusive boronizing of nodular iron, especially the influence of boron concentration on the hardness of the achieved surface layer. This research is a part of study on application of LHT to gray iron surface layer. The general purpose of this study is to improve useful properties of machine part made of gray iron.

2. Methodology

Nodular iron 500-7 with pearlite-ferrite matrix and spheroidal graphite was chosen as the test material (Fig. 1).

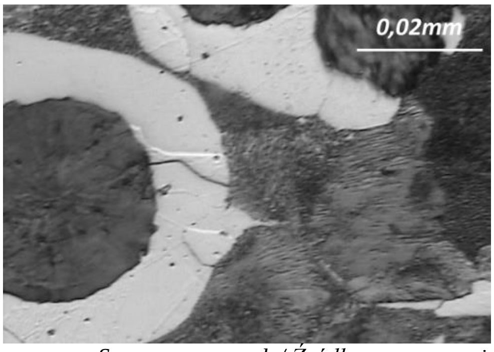

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Fig. 1. The microstructure of the 500-7 nodular iron. Etched with nitride acid solution

Rys. 1. Mikrostruktura żeliwa sferoidalnego EN-GJS0500-7. Trawione nitalem

The chemical composition of investigated iron is presented in Table.

One sample of nodular iron was modified by diffusion chemical-heat treatment and the second one by laser alloying. Diffusion boronizing consists in the saturation with the element of surface layer of tested material using gas method. The sample was heating for 4 h in temperature of 950ºC. Laser boronizing consists in alloying the surface layer with the element using heating by laser beam. Before laser heating the sample was covered with the paste containing an alloying substance (the powder of amorphous boron: size of particles <1 μm; purity ≥95%; Sigma-Aldrich – Fig. 2) and a bonding substance (the water glass). The thickness of the covering paste was approx. 0,040 mm. Laser beam caused simultaneously melting of the alloying substance with thin layer of covered material.

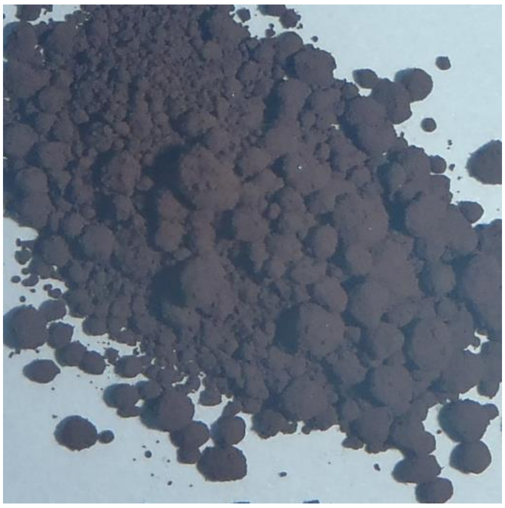
Then, those melted materials were mixed and rapidly cooled. As a result, a new alloy, different from material of nodular iron and paste with boron, was created. Molecular CO_2 continuous Triumph laser type TLF 2600 t with 2.6 kW output power and $TEM_{0.1}$ mode was used. Laser beam power density was 33 $W \cdot mm^{-2}$ and its scanning velocity was 196.8 $mm \cdot min^{-1}$.

Table. The chemical composition of EN-GJS-500-7 nodular iron

Tabela. Skład chemiczny żeliwa sferoidalnego EN-GJS-500-7

Cast iron	The element value % [wt.]							
	C	Si	Mn	P	S	Cr	Cu	Mg
EN-GJS-500-7	3.82	2.53	0.33	0.042	0.013	0.02	0.257	0.06

Source: own work / Źródło: opracowanie własne a)



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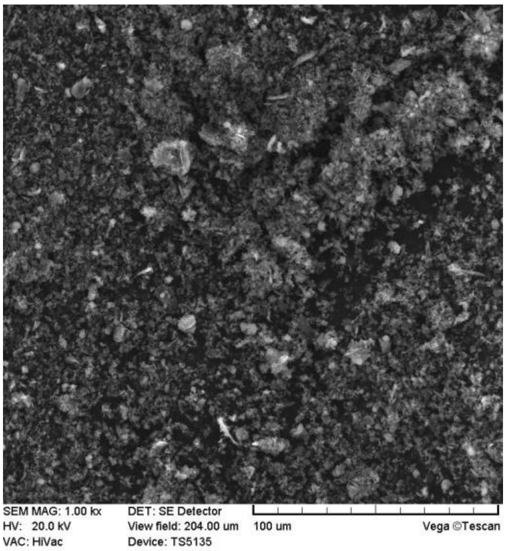

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Fig. 2. Boron powder: macroscopic image (a), scanning electron microscopic image (b)
Rys. 2. Proszek boru: zdjęcie makroskopowe (a), obraz z mikroskopu skaningowego(b)

The results of the diffusion and laser treatment were analyzed by means of Neophot optical microscope and Vickers hardness tester (ZWICK, 3212) with 100G of load (microhardness distribution on the section of modified zones determination).

To evaluate the concentration of such light element as boron, Auger electron spectroscope (RIBER, LAS 620) was applied. This spectrometer allows to execute single measurement of 2 μm diameter area, which reflects the size of original electron beam causing Auger process. Auger electrons escape from maximum depth of 10Å. “Peak to peak” value in the Auger spectrum is proportional to the element concentration in the sample.

The investigation was performed at the Institute of Machines and Motor Vehicles, Poznan University of Technology.

3. Results and discussion

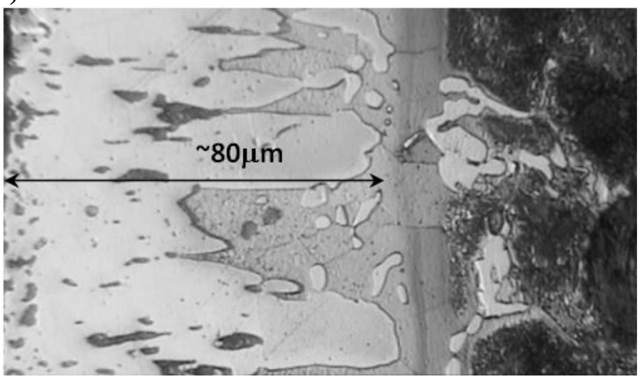
After diffusion, as well as, after laser treatment of nodular iron boronized zone was detected. The microstructure across the surface layers obtained after diffusion and laser treatment is presented in the Fig. 3.

Coarse-grained, needle-like shape of iron borides and ferrite grains were observed after diffusive boronizing (Fig. 3a). Some remains of graphite and porosity were also noticed in this case. Whereas, very fine-crystalline microstructure after laser alloying was created (Fig. 3b). It is characteristic for laser treatment with remelting. In boronized zone (especially near the surface) very homogenous area was found. Dendritic microstructure was noticed as well. It was especially visible in the vicinity of the border with non-remelted material during treatment. Some graphite nodules (partly diluted) stayed in the boronized zone.

Auger electron spectroscopy allowed to identify boron in the both modified surface layers. “Peak to peak” values for boron were evaluated on the basis of Auger spectrums. The example of AES spectrum for the nodular iron surface layer after laser alloying is presented in the Fig. 4.

Boron concentration distribution represented by “Peak to peak” value on the section from the surface to the core material after diffusion treatment was juxtaposed together with hardness distribution and shown in the Fig. 5. It could be noticed that, boronized zone did not exceed 100 μm. Changes in boron amount reflects inhomogeneity in microstructure obtained after diffusion treatment. Results of analysis of hardness distribution confirmed such character of microstructure. Quite huge scatter of hardness from 300 to 1400HV0.1 was evidence of the existence of hard (iron borides), and soft phases (ferrite, some remains of graphite nodules) in surface layer created by diffusion treatment.

a)



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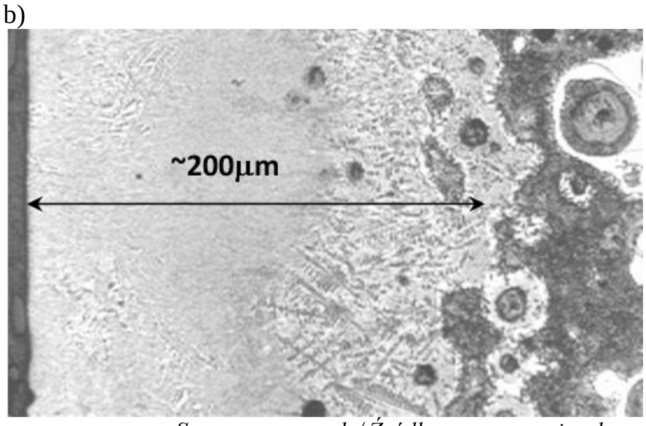

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Fig. 3. The microstructure of the boronized zone by diffusion (a) and laser (b) treatment. Etched with nitride acid solution
Rys. 3. Mikrostruktura strefy naborowanej przez obróbkę (a) dyfuzyjną i (b) laserową. Trawione nitalem

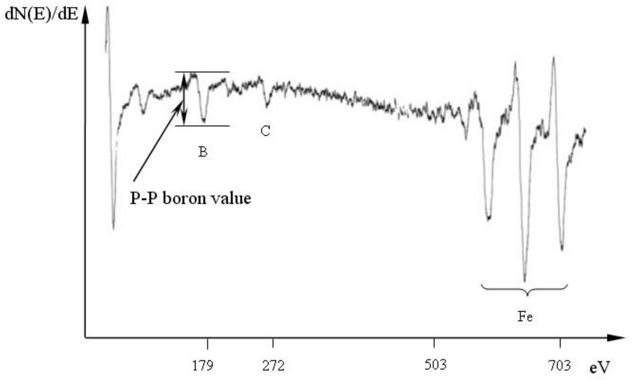

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Fig. 4. The example of AES spectrum for the nodular iron surface layer after laser alloying
Rys. 4. Przykładowe widmo AES dla warstwy wierzchniej żeliwa sferoidalnego po stopowaniu laserowym

AES research of boron concentration (Fig. 6) confirmed the maximum depth of laser boronized zone noticed during microstructure observations – Fig. 3b (approx. 200 μm). Boron distribution, as well as, hardness distribution is much different in case of laser boronized surface layer of nodular iron. Unlike the surface layer created after diffusion boronizing little changes in boron amount reflects higher homogeneity and fine grained microstructure obtained after laser treatment. Boron concentration is quite constant to approx. 80 μm and then, gentle decrease could be observed on the border of boronized zone. In this first part in the laser boronized zone on the section from the surface average hardness was about 1300HV0.1 and in the second part some decrease was noticed. Average microhardness in this part was below 1200HV0.1. Much less scatter of boron concentration, as well as hardness could be noticed in case of the surface layer obtained by laser treatment then diffusion treatment.

Analysis of boron concentration and hardness results showed significant differences between effects in the surface layer of both boronizing types. However, the influence of boron concentration on achieved hardness of modified surface layer was observed. Some correlation between boron concentration and hardness was found (Fig. 7).

It could be noticed, that the hardness depends more on boron concentration in case of diffusion treatment than the hardness obtained by laser treatment (the factor of the slope of the line *a* was almost 6-times bigger for diffusion treatment than for laser treatment). During analysis of the hardness results it is crucial to take into account some other factors (except boron concentration) influencing strengthen of the surface layer like: size, shape, type of created phases, as well as the degree of their supersaturation. Consequently, smaller dependence of the hardness on boron concentration in case of laser treatment is caused by such factors. The hardness after laser alloying is increased not only by new hard phases (like boride iron in case of boronizing) but also by very fine microstructure and supersaturated solid solutions.

Therefore, it could be stated, that to achieve the same hardness in case of laser boronizing less boron could be implemented to the surface, than in case of diffusion boronizing. It could favor in laser treatment selection as a method of nodular iron surface boronizing.

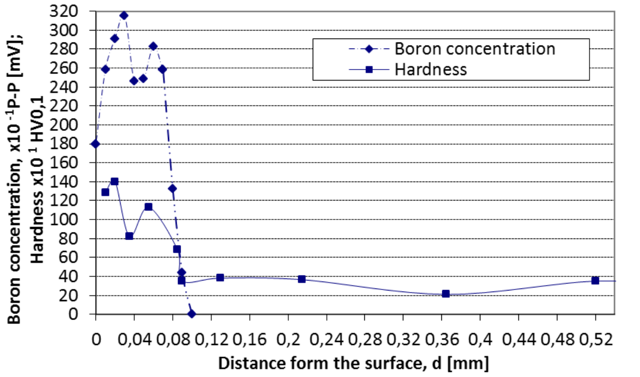

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Fig. 5. Change in boron concentration distribution and hardness distribution in the surface layer of nodular iron after diffusion treatment
Rys. 5. Zmiany stężenia boru oraz zmiana twardości w warstwie wierzchniej żeliwa sferoidalnego po obróbce dyfuzyjnej(opracowanie własne)

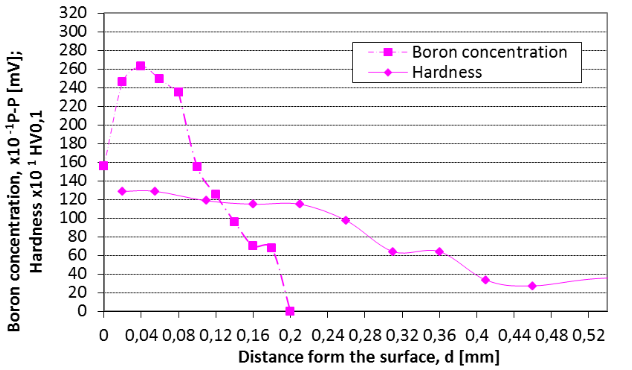

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Fig. 6. Change in boron concentration distribution and hardness distribution in the surface layer of nodular iron after laser treatment
Rys. 6. Zmiana stężenia boru oraz zmiana twardości w warstwie wierzchniej żeliwa sferoidalnego po obróbce laserowej(opracowanie własne)

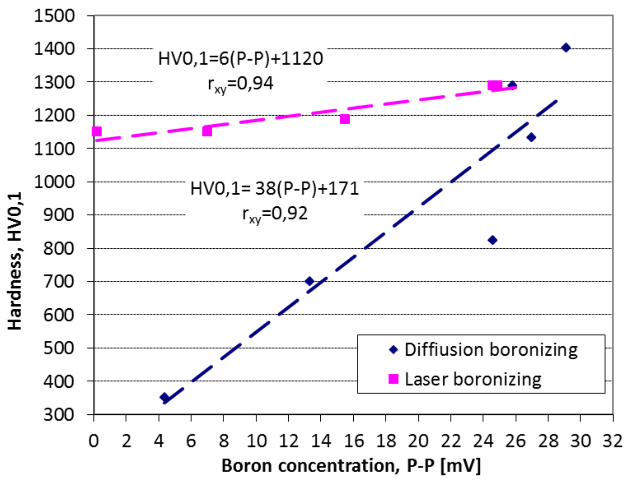

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Fig. 7. The correlation between boron concentration and hardness in the surface layer of nodular iron in case of diffusion and laser boronizing
Rys. 7. Zależność pomiędzy zawartością boru i twardością w warstwie wierzchniej żeliwa sferoidalnego w przypadku borownia dyfuzyjnego i laserowego

4. Conclusion

The following conclusions can be drawn from the carried out research.

After diffusion and after laser boronizing of the nodular iron surface layer boronized zone with higher hardness (in comparison to the hardness of the core material) was detected. Coarse-grained, needle-like shape of iron borides with ferrite grains after diffusion boronizing and very fine-crystalline microstructure after laser heat treatment were observed.

Hardness changes in the surface on the cross-section for both methods of boronizing were correlated with boron concentration. Nevertheless, this correlation was stronger for diffusion boronizing than for laser heat treatment. Smaller correlation for the zone achieved after laser boronizing is probably a result of other aspects which are characteristic for laser treatment with remelting like supersaturated solid solutions or very fine grains (unlike effects of diffusion boronizing).

The performed research showed that it is possible to use less of alloying element in case of laser treatment to achieve similar hardness of the surface layer after diffusion modification. Higher microstructure homogeneity, gentle hardness changes on the cross section of the surface layer from the surface to the core material after laser boronizing (in comparison to diffusion boronizing) should favor the wear resistance increase of the cast iron used in machine part and be conducive to the selection of this kind of treatment.

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