LBL-15654
Preprint c.2

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Materials & Molecular Research Division

RECEIVED
LAWRENCE
BERKELEY LABORATORY

MAY 17 1983

LIBRARY AND
DOCUMENTS SECTION

To be submitted for publication

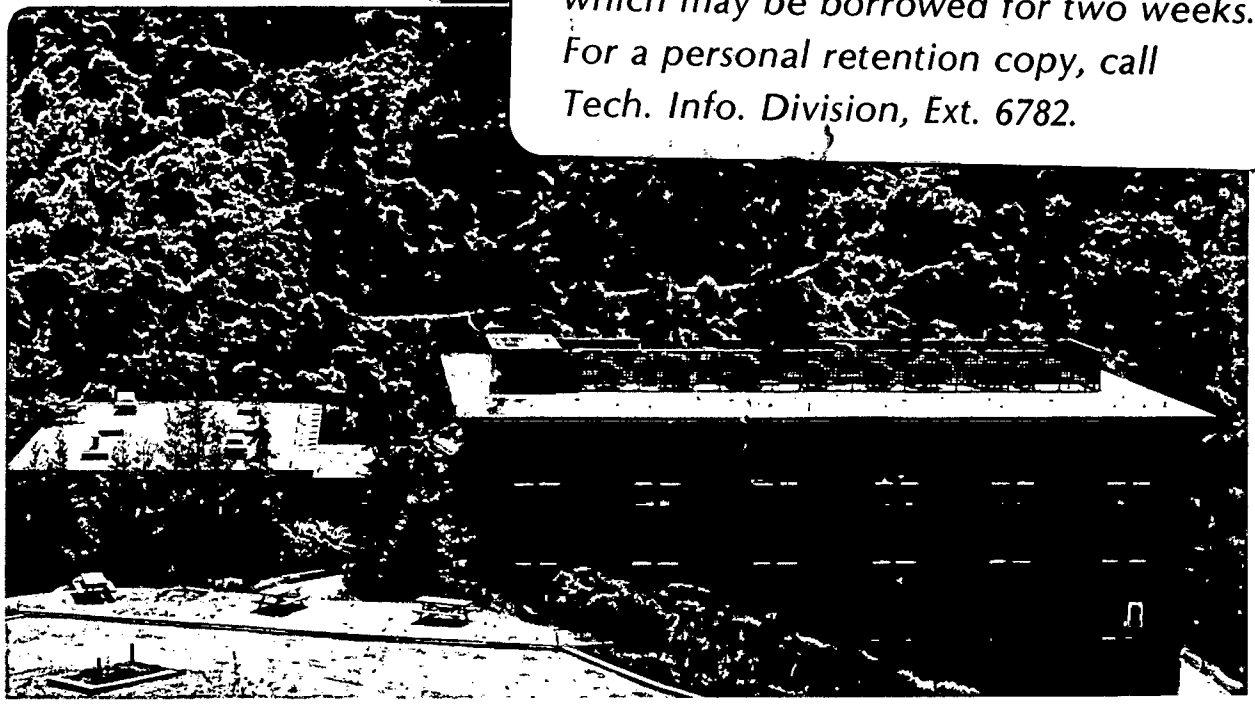
SOME PRELIMINARY OBSERVATIONS ON THE SLIDING WEAR BEHAVIOR AND MICROSTRUCTURE OF A LASER HEAT-TREATED EXPERIMENTAL ALLOY

J.J. Rayment, G. Thomas, W.J. Salesky, and X.M. Meng

February 1983

TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks. For a personal retention copy, call Tech. Info. Division, Ext. 6782.



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

LBL-15654 c.2

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

SOME PRELIMINARY OBSERVATIONS ON THE SLIDING WEAR BEHAVIOR AND MICROSTRUCTURE OF A LASER HEAT-TREATED EXPERIMENTAL ALLOY

J. J. Rayment and G. Thomas

Department of Materials Science and Mineral Engineering and the

Materials and Molecular Research Division

Lawrence Berkeley Laboratory

University of California

Berkeley, CA 94720

W. J. Salesky

Smith Tool Company

17871 Von Karman Avenue

Irvine, CA 92713

X. M. Meng

Wuhan Research Institute of Materials Protection

180 Pao Feng Er Lu

Wuhan, People's Republic of China

Introduction

Recently, a strong, tough experimental alloy Fe/3Cr/2Mn/0.5Mo/0.3C, has been developed which possesses good wear resistance in comparison to commercial, wear-resistant alloys (1-3). To exploit this result further, the same alloy has undergone a localised, surface heat-treatment using a 500 watt, continuous wave CO_2 laser. Such a heat-treatment has been previously shown to result in an increase in the hardness as well as the refinement of the microstructure in the heat-affected zone (HAZ) (4,5). In the present work, different laser beam traverse velocities and multiple laser pass geometries (adjacent and overlapping), have been used to examine their relative effect upon the subsequent microstructure, hardness and sliding wear behavior.

Experimental

The Fe/3Cr/2Mn/0.5Mo/0.3C alloy was obtained by vacuum-induction melting, courtesy of Daido Steel Company, Japan. Once cast, the ingot was cross-forged and then homogenized for 24 hours at 1200°C. After homogenization two types of specimen were prepared; (a) 2.54 cm (1") x 7.62 cm (3") x 0.635 cm (0.25") plates were machined, ground and then finally annealed at 1100°C for 1 hour and then oil-quenched. These specimens were intended for metallographic and microhardness examination; (b) rod of 1.27 cm (0.5") diameter was rolled down from the homogenized alloy and cut into sections 1.27 cm long (0.5"). A further high temperature homogenization (1200°C for 24 hours) was carried out to remove the deformation introduced by the rolling. Once homogenized, half the length was removed by machining down to 0.635 cm (0.25") to form a flat-ended stud. These studs, after a final anneal at 1100°C for 1 hour, were intended for modified pin-on-

disc sliding wear testing. The final microstructure of both types of specimen was lath martensite, with some autotempered carbides, and thin interlath films of retained austenite (6). The laser heat-treating was carried out at Coherent Laser Inc. of Palo Alto, CA using a 500 watt cw CO_2 laser. All specimens were surface ground, cleaned and then coated with a colloidal graphite layer to aid in the absorption of energy from the laser beam. Both the plates and the studs were mounted in inserts cut into a large copper block, allowing a large conductive mass to remove the heat away from the specimens during the laser heat-treatment. The block and specimens were placed upon a numerically controlled x-y table, and subsequently irradiated with a continuous laser beam of 500 watts working power, using a 12.7 cm (5") cylindrical lens, producing an elliptical, defocussed spot of ~ 5 mm width. The surface of the specimens was scanned by the beam at velocities ranging from 5.08 mm/sec (0.2"/sec) up to 10.16 mm/sec (0.4"/sec). In order to examine the effect of multiple laser passes, that is to ascertain the way in which the second laser pass affects the microstructure and properties of the prior pass, the laser was programmed to scan the surface of the specimens in successive passes using two different configurations; adjacent passes and overlapping passes (~ 30% overlap).

All wear testing was performed using a pin-on-disc wear machine as described elsewhere (3). Conventionally, the pin is hemispherically tipped, but because such a geometry would be difficult to uniformly heat treat with a laser, a flat-ended stud was used as described above. To remove start and stop marks produced by the laser, a 0.32 cm (0.125") diameter island was machined. To provide a basis for comparison, specimens that had undergone only the conventional heat-treatment were tested under equivalent conditions. The disc material used was AISI 52100 flat steel with a hardness of $62.5R_c$. Wear tests were carried out in

air under a dead weight of 5 kilograms, without lubrication. The 'pins' traversed the freshly ground surface of the disc in the same wear track for a distance of 750 metres. The amount of pin-wear was monitored and continuously recorded during each test, by measuring the downward vertical displacement of the pin as a function of time using a linear variable displacement transformer (LVDT). To compliment this data, the volume loss resulting from wear was determined by measurement of the weight difference of the pin before and after testing.

Both optical metallography and scanning electron microscopy were performed to characterize the microstructure. Specimens were cut from the laser heat-treated regions, mounted in cold-mount resin, abraded down to 600 grit and then polished in stages down to 0.05μm scratch size. The polished specimens were etched in a 5% Nital solution. Optical metallography was carried out on a Zeiss Metallograph microscope, and scanning electron microscopy on an ISI DS-160 electron microscope. Microhardness testing was performed using a Leitz microhardness tester with either a Knoop or a Vickers diamond indentor.

Results

Figure 1 is an optical micrograph of the transverse section of a single laser pass (velocity 5.08 mm/sec). The lighter region shown is the laser heat-treated zone, or more commonly, the heat affected zone (HAZ) which has undergone rapid heating during the laser process, and the area immediately adjacent to the HAZ is the tempered zone, which has been indirectly tempered during the process. The structure within the HAZ is difficult to etch, because of the effect of such rapid heating/quenching, but it is possible to distinguish two separate microstructural regions. There is an inner region (region A) which is martensitic with a prior austenite grain size of 25-50 μms, and an outer region

(region B), surrounding it, which is also martensite, but has a prior austenite grain size of 200-250μms. Specimens that are laser heat-treated at the lower speeds (5.08 mm/sec and 6.35 mm/sec) also exhibit some surface melting, albeit to depths no greater than 15 μms. No surface melting is observed in specimens processed at the higher laser velocities. The dimensions of the HAZ as well as the relative proportions of the two different regions within it, are found to be dependent upon the traverse velocity. Figure 2 shows the maximum depth attained as a function of the traverse velocity for laser heat-treated Fe/3Cr/2Mn/0.5Mo/0.3C. As shown, the depth of the HAZ decreases with increasing velocity. Concomitant with this decrease in depth is a decrease in the width of the HAZ. At 5.08 mm/sec, the width of a single pass is ~ 5.5mm whereas at 8.89 mm/sec the width is only ~ 4.5 mm. The width of region A is also reduced; at the lower speed, region A was ~ 4.0 mm wide, but at the higher speed, it had shrunk to ~ 2.0 mm in width. The depth to which region A extends is difficult to measure accurately because of the small degree of etching that occurs, but it is approximately to 150μms at 5.08 mm/sec and 50-75μms at 8.89 mm/sec.

Figures 3a and 3b are SEM micrographs typical of the top surface of regions A and B respectively. They show clearly the martensitic nature of the HAZ, and the difference in grain size between the two regions. Figure 4 shows the profiles of microhardness as a function of depth in transverse sections of specimens processed at the different beam velocities. All profiles show a high hardness of ~ 600 VHN in the heat affected zone, in comparison to a matrix hardness of ~ 450 VHN (~ $45R_C$). In addition they all show a dropping off of the hardness near the boundary between the HAZ and the adjacent tempered zone. The tempered zone, which has undergone indirect tempering as a consequence of the laser heat-treatment, exhibits a hardness of ~350 VHN, which is lower than the matrix hardness and extends to depths 150-250μms below the HAZ, depending upon the

beam velocity. Figures 5 and 6 show the variation of microhardness across the surface of two laser passes in the adjacent and overlapping configuration respectively. They show similar results inasmuch as in both cases the second pass tempers and thus softens a portion of the HAZ of the prior pass, and furthermore the distance over which tempering occurs appears to be the same. However, because overlapping does occur in the latter configuration, the tempered region is repeated more often than in the former configuration. An interesting result that is observed is that in the untempered regions of the HAZ, the grain size appears to have little effect upon the microhardness.

Although five different laser velocities were used, just two were selected to investigate the effects of laser heat-treatments and the processing parameters upon the sliding wear behavior. These two velocities, 5.08 mm/sec (0.2"/sec) and 8.89 mm/sec (0.35"/sec) were chosen in an attempt to determine the effect, if any of (i) the presence or absence of surface melting (and indirectly the dwell time), and (ii), the small-grain central region which becomes less extensive at the higher speeds. Figure 7 shows the results for both the continuous wear measurement as well as the ultimate weight loss. Both experiments show that all the laser heat-treated specimens have a significantly greater wear-resistance than that of the conventionally heat-treated steel, and more specifically, the specimen with the least wear is that processes in an adjacent pass configuration, at 8.89 mm/sec (0.35"/sec). There is some disagreement about which specimens show the penultimate wear; the continuous measurement experiment shows that 5.08 mm/sec (0.2"/sec) in an adjacent pass mode wears less than the specimens processed at 8.89 mm/sec (0.35"sec) in an overlapping mode, whereas the order is reversed for the total weight loss measurement. Both experiments, however, show that specimens processed 5.08 mm/sec (0.2"/sec) in an overlapping configuration have the highest rate of wear.

Discussion

The occurrence of two distinct microstructural regions has not often been reported, but is almost definitely a consequence of the processing. Previously reported work on laser heat-treatment has been carried out using a cw CO_2 laser of considerably higher power (1-5 kwatts) than is used in the present work (5,6). Such high power levels were thought necessary to achieve enough local heating to cause transformation or surface hardening. However, it is now possible to effectively use a power level of only 500 watts by defocussing the beam sufficiently to produce a near-elliptical beam pattern. The power density distribution that results appears, therefore, to concentrate the majority of the power in the central region of the beam and must drop off quite sharply in order to produce such a well-defined boundary between region A and region B (Fig. 1). Region A, the small-grained region has obviously been heated to a temperature above the A_3 and below the liquidus, allowing the transformation of the original martensite structure to austenite and the subsequent transformation back to martensite although with a smaller prior austenite grain size, during cooling. In the outer large-grained region, region B, it is apparent that either insufficient heating or time for the diffusional reaction has occurred, and thus the $\alpha' \longrightarrow \gamma$ transformation does not take place. This is shown clearly in the microstructural examination of the boundary between region B and the tempered matrix in which grains and grain boundaries are found common to both areas.

Both the hardness and microstructural results show that the high hardness of the HAZ is not caused solely by the refinement of the grain size; the hardness is constant throughout the HAZ, although there are two regions within the HAZ, with distinctly different grain sizes. The hardness is caused by the presence of residual

compressive stress within the HAZ. The existence of compressive stresses in laser heat-treated specimens is well-documented (7), but its probable contribution to the hardness has often been overlooked. Some preliminary X-ray diffraction measurements of the amount of compressive stress present yield a value of ~ 500MPa, in good agreement with results obtained by other workers (7).

The wear results show that laser heat-treatment Fe/3Cr/2Mn/0.5Mo/0.3C can lead to a beneficial increase in the alloy's sliding wear resistance through its effect upon the microstructure, hardness and level of compressive stress. It appears that specimens laser heat-treated in an adjacent pass configuration, at a beam velocity of 8.89 mm/sec (0.35"/sec) yield the best results. It is not altogether clear why the faster beam velocity should show the lesser wear, although the absence of a thin melted layer may account for the variation in wear rate observed at the beginning of the continuous wear measurement test. It is likely, however, that the adjacent pass configuration gives the better wear resistance because of the fewer tempered, softer regions that occur in the multi-pass specimens as compared to the overlapping pass specimens.

Conclusions

Laser heat-treatment of Fe/3Cr/2Mn/0.5Mo/0.3C results in the following:

i) a heat-affected zone with two regions; a central region consisting of lath martensite with a prior austenite grain size of 25-50μms, and an outer region of lath martensite with a prior austenite grain size of ~200-250μms.

ii) a relatively constant hardness of ~600 VHN within the HAZ, as compared to a matrix hardness of ~400-450VHN.

iii) a substantial increase in the sliding wear resistance as compared to the conventionally heat-treated alloy.

iv) a high level of compressive stress in the surface treated layer that appears to contribute to the hardness and hence to the sliding wear resistance.

Acknowledgements

This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Science Division of the U. S. Department of Energy under Contract No. DE-AC03-76SF00098. The authors would like to acknowledge Coherent Lasers, Inc., Palo Alto who performed all the laser processing and Dr. R. M. Fisher (U. S. Steel corporation) for helpful discussions. In addition one of the authors (X.M.) would like to thank NATO for provision of a visiting fellowship.

References

1. W. J. Salesky and G. Thomas, Wear 75, 21 (1981).
2. C. K. Kwok, M. S. Thesis, University of California, Berkeley (1982).
3. W. J. Salesky, Ph. D. Thesis, University of California, Berkeley (1982).
4. F. D. Seaman and D. S. Gnanamuthu, Metal Progress 8, 179 (1975).
5. P. A. Molian, Mat. Sc. and Eng. 51, 253 (1981).
6. M. Sarikaya, B. Steinberg and G. Thomas, Met. Trans. 13A, 2227 (1982).
7. D. S. Gnanamuthu, Source Book on Applications of the Laser in Metalworking, p. 324, ASM, (1981).

Figure Captions

Fig. 1. Transverse section of a single laser pass; traverse speed -5.08 mm/sec.

Fig. 2. Depth of laser heat-treated region as a function of laser traverse speed.

Fig. 3a. SEM micrograph of the small-grained region A within the laser treated layer.

Fig. 3b. SEM micrograph of the large-grain region B within the laser-treated layer.

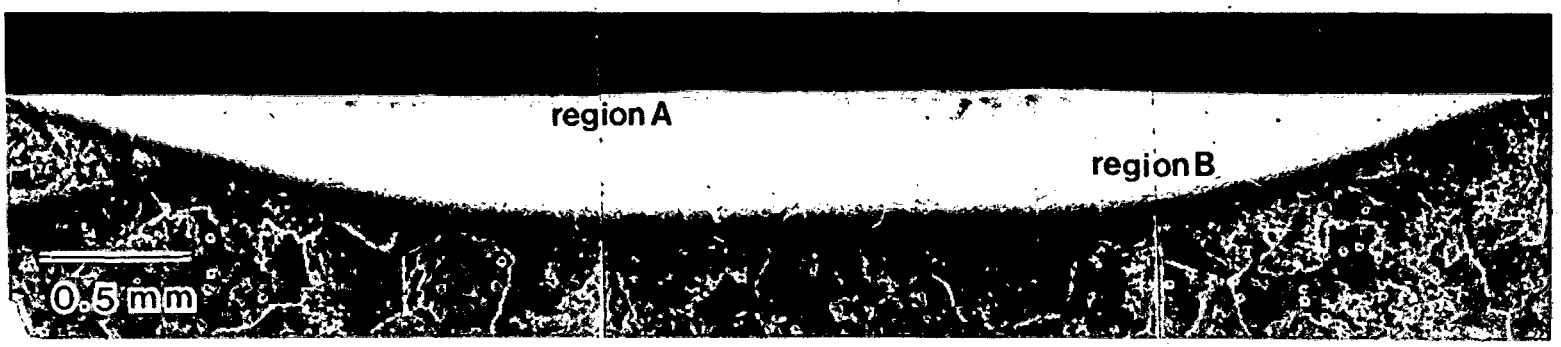
Fig. 4. Microhardness as a function of depth in transverse sections of the laser-treated region, for each of the different traverse speeds.

Fig. 5. Microhardness as a function of microstructure across the surface of two adjacent laser passes (8.89 mm/sec)

Fig. 6. Microhardness as a function of microstructure across the surface of two overlapping passes (7.62 mm/sec).

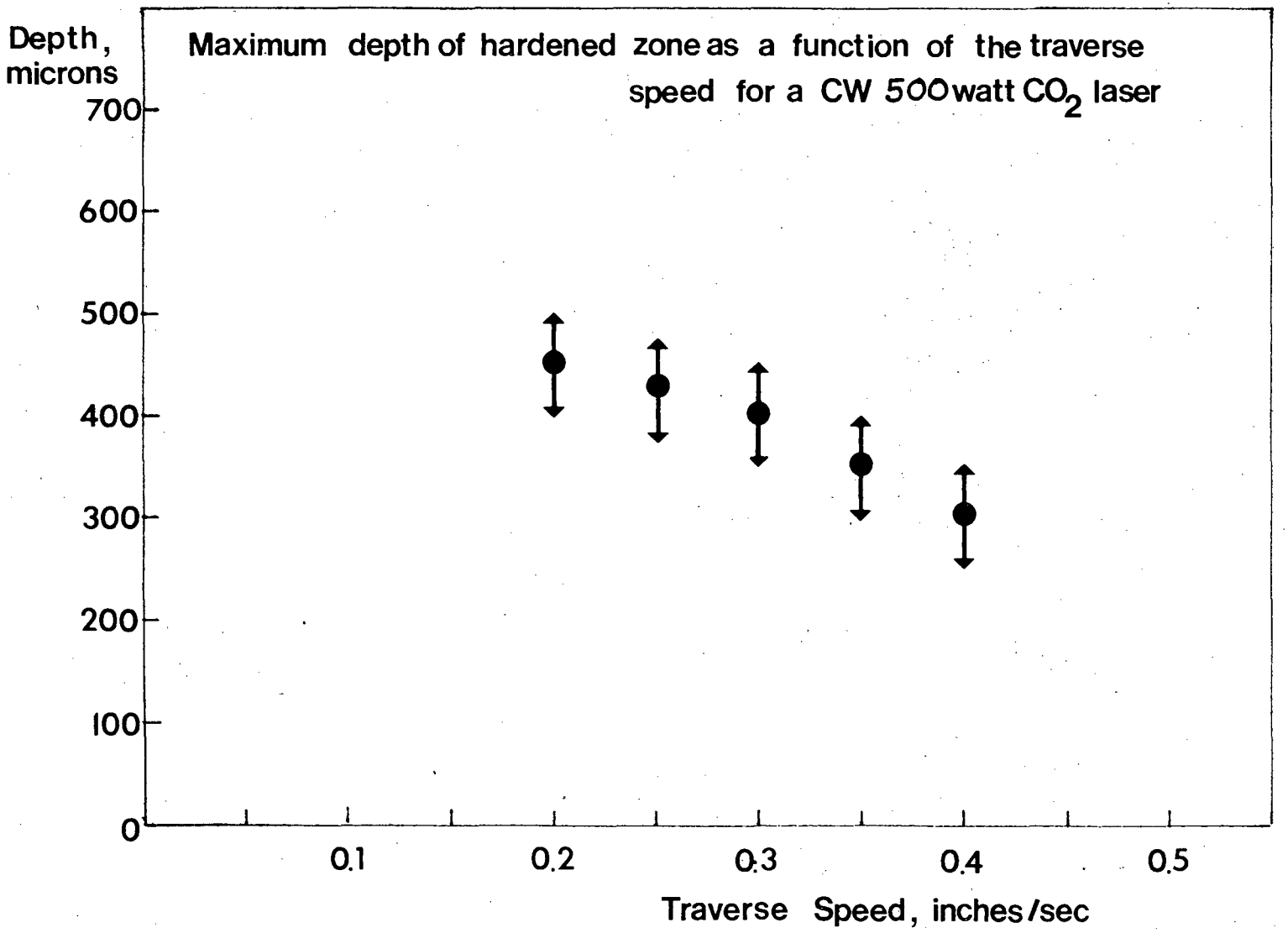
Fig. 7a. Amount of wear as a function of sliding distance for conventional and laser heat-treated specimens.

Fig. 7b. Weight loss observed during the sliding wear testing of conventional and laser heat-treated specimens.



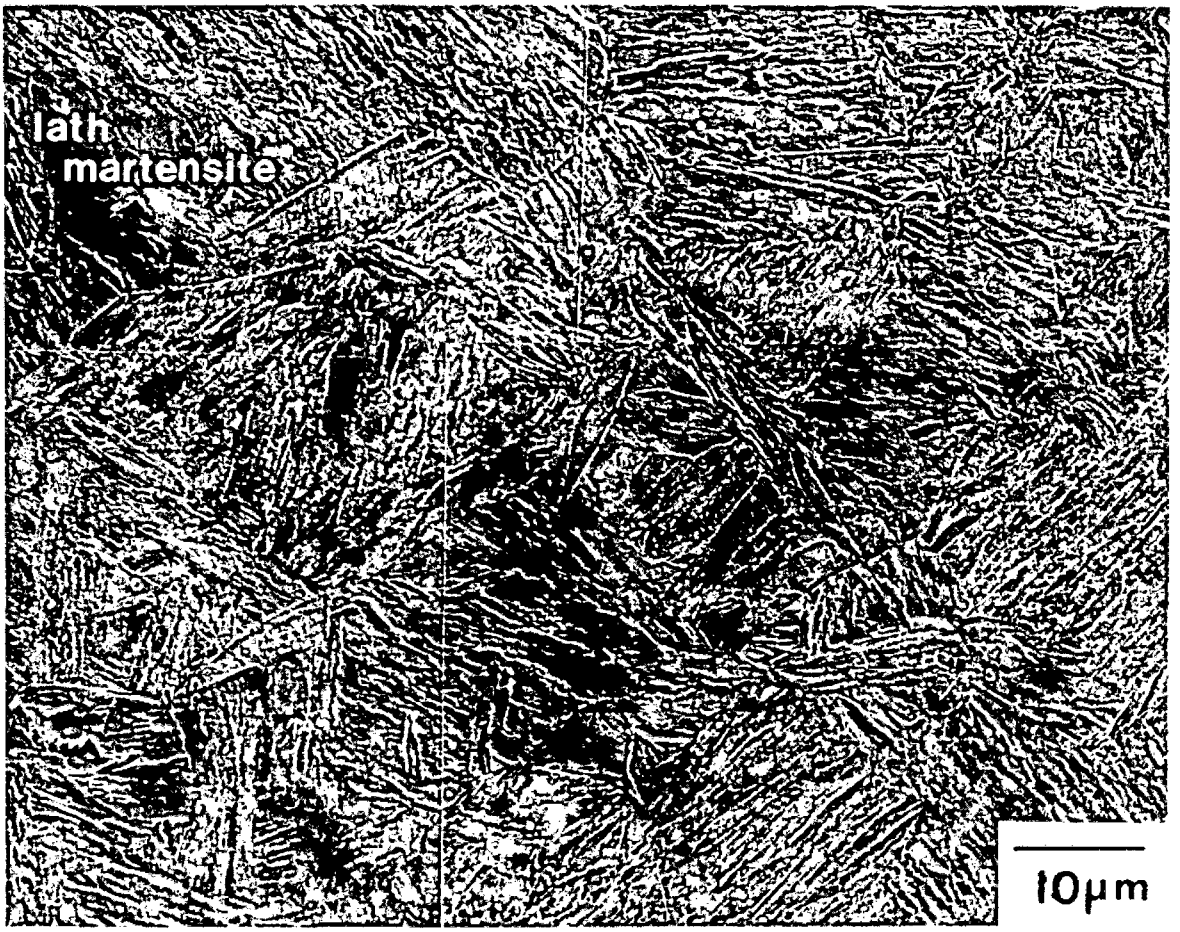
XBB 832-1644

Fig. 1



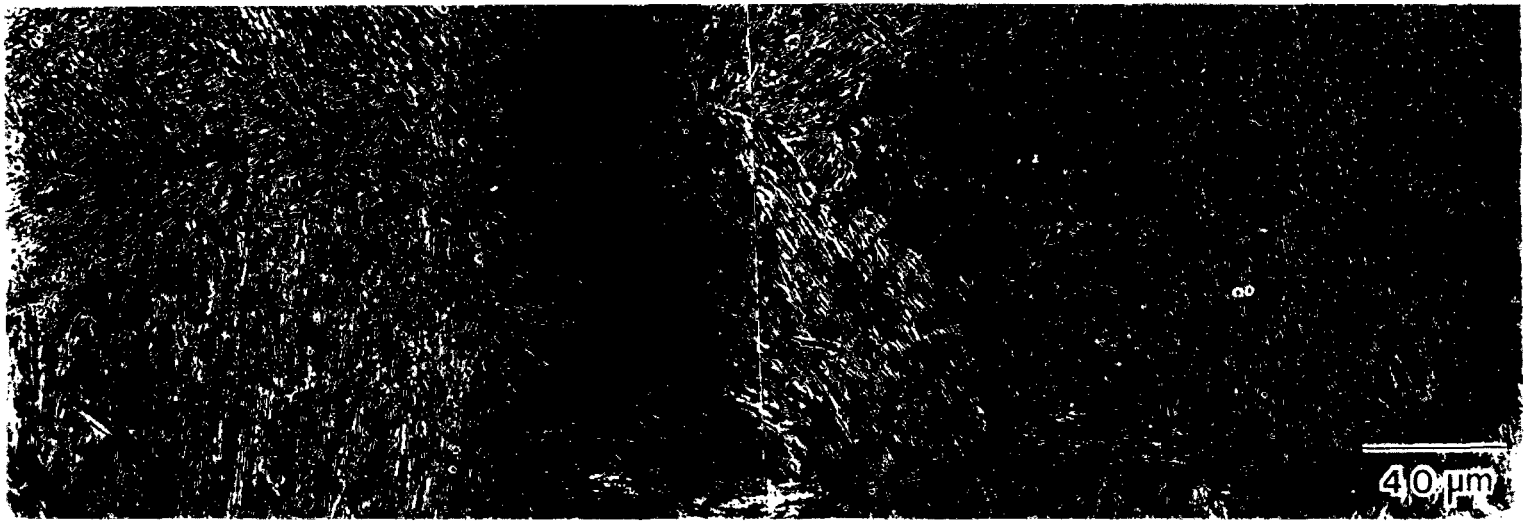
XBL 824-9104

Fig. 2



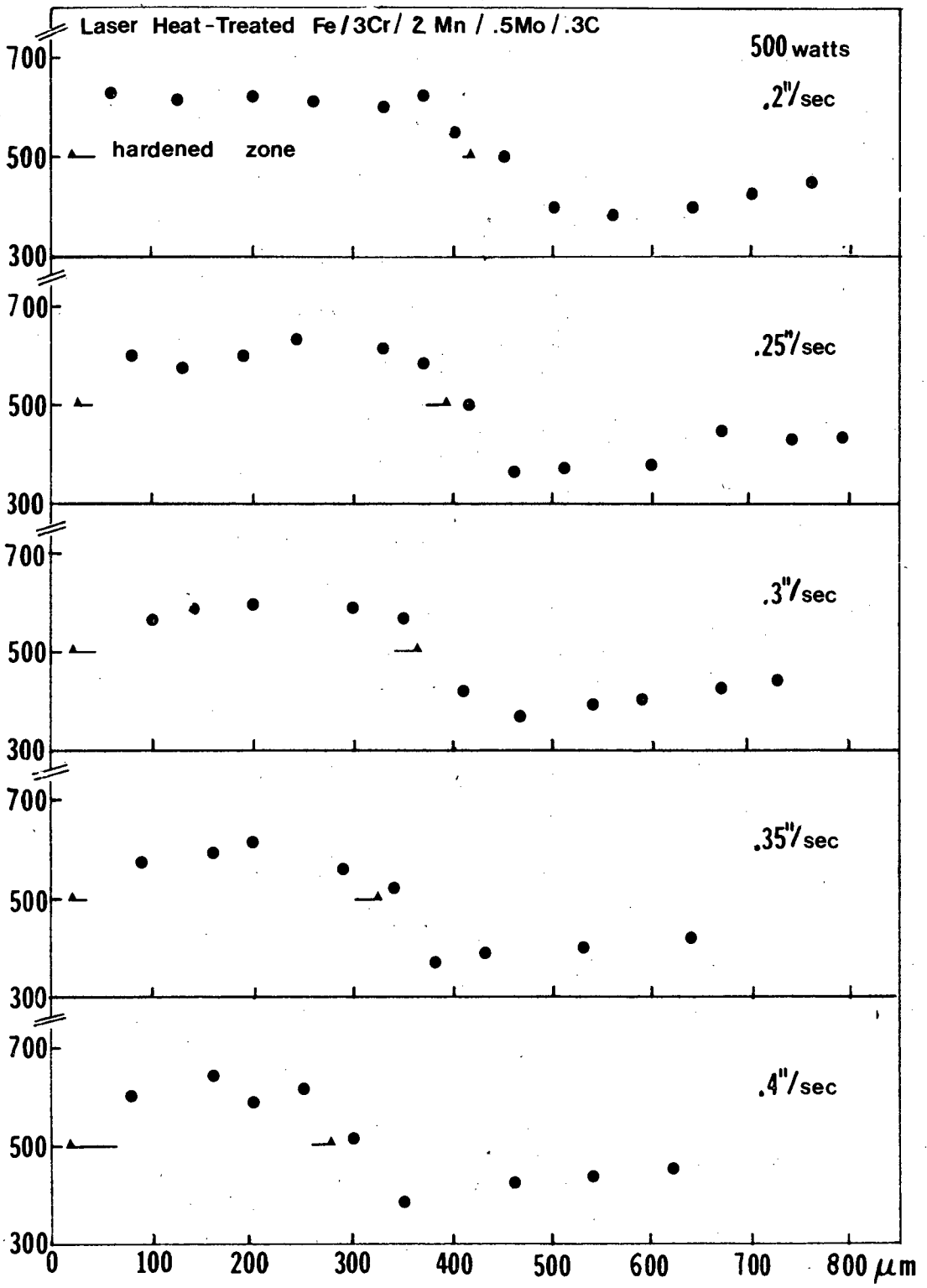
XBB 831-14

Fig. 3a



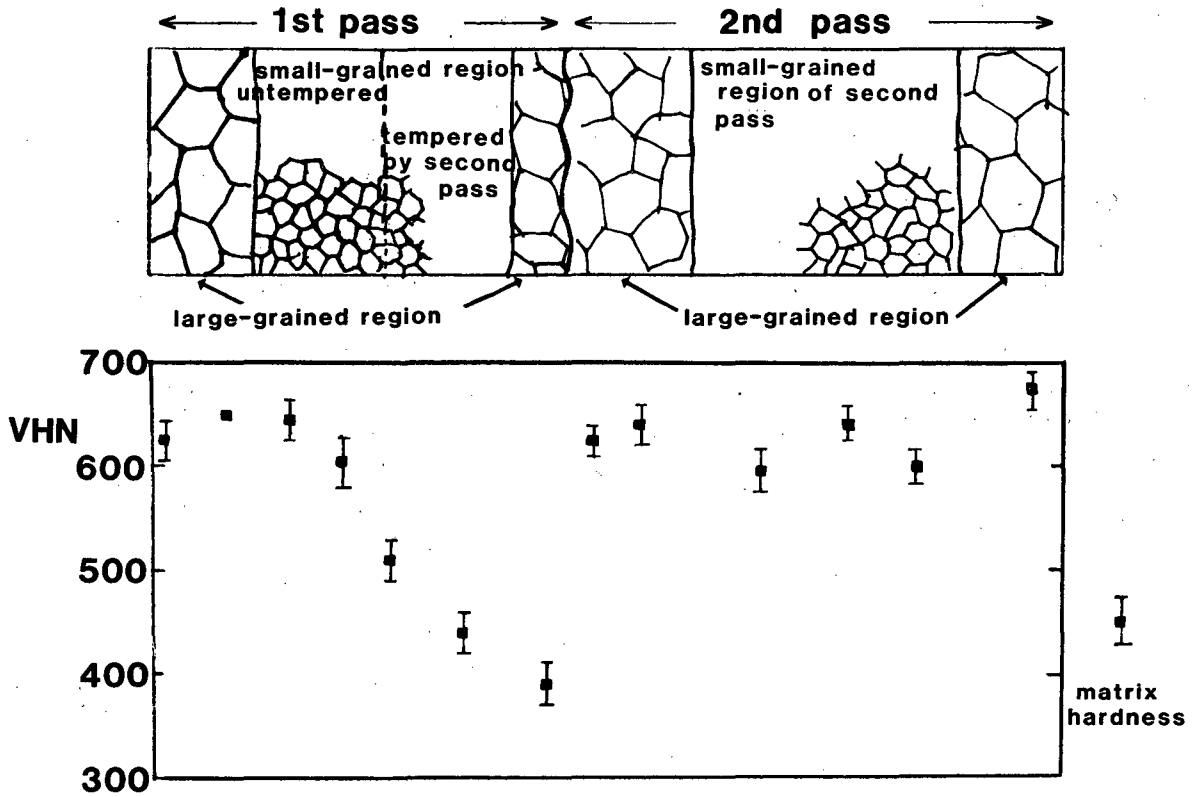
XBB 831-21

Fig. 3b



XBL 832-8424

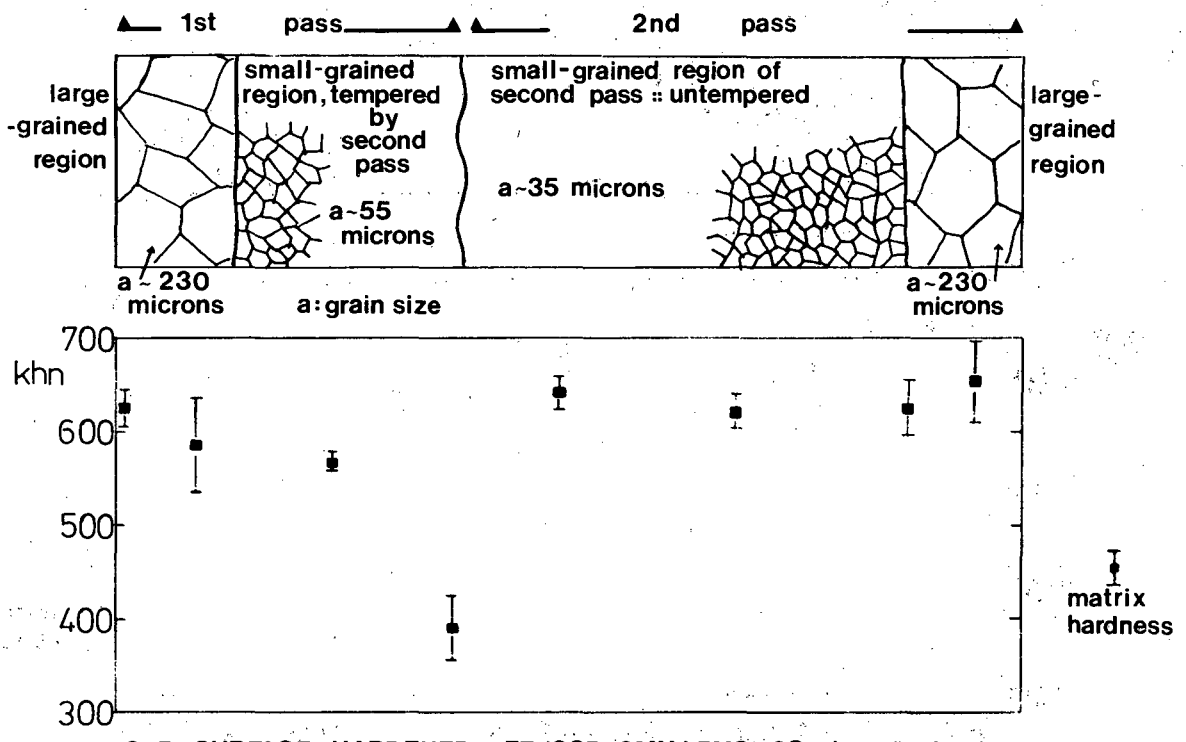
Fig. 4



LASER SURFACE-HARDENED FE/3CR/2MN/.5MO/.3C the microhardness across two adjacent laser passes, at 0.35 inches per second

XBL 832-8423

Fig. 5



LASER SURFACE-HARDENED FE/3CR/2MN/.5MO/.3C: the microhardness across two overlapping laser passes, at 0.3 inches per second

XBL 826-10343

Fig. 6

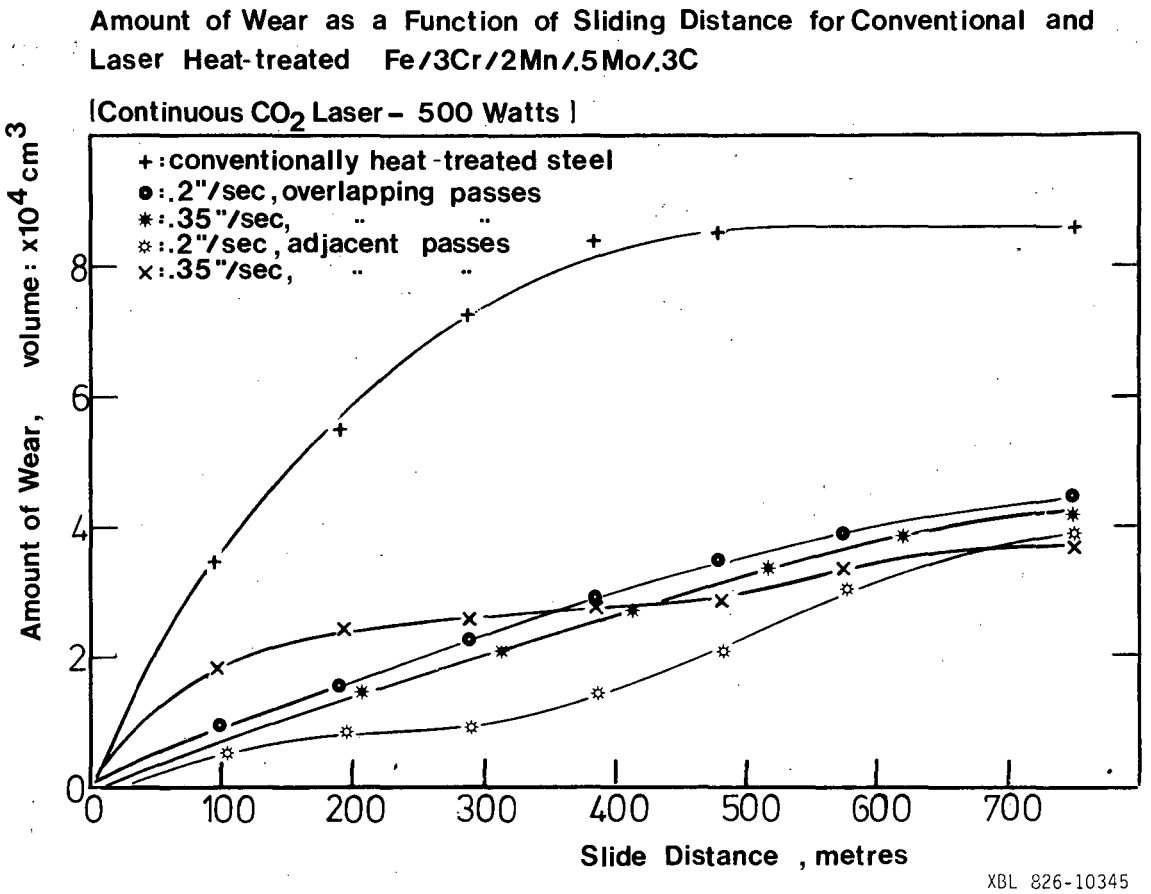
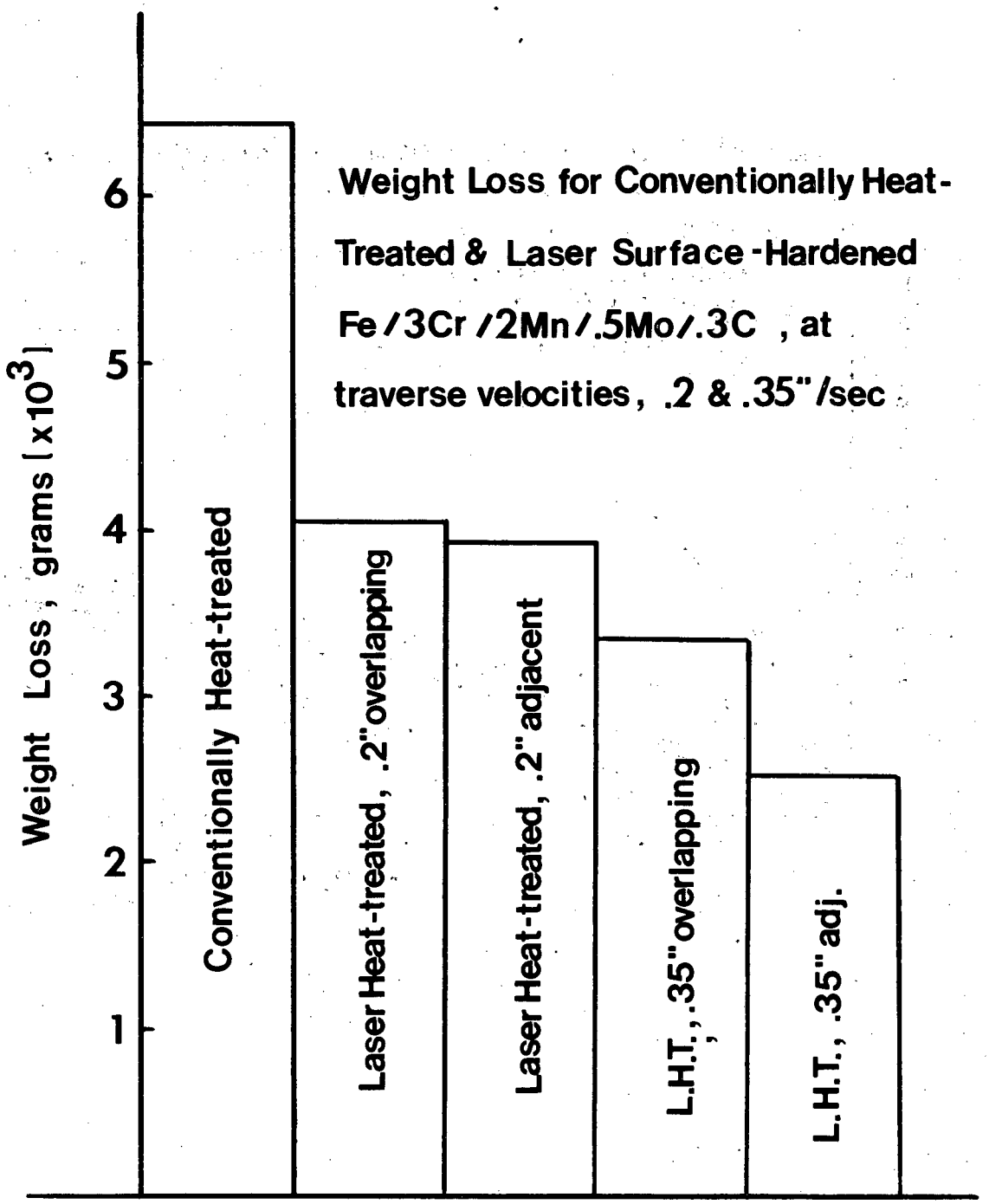

Amount of Wear as a Function of Sliding Distance for Conventional and Laser Heat-treated Fe/3Cr/2Mn/.5Mo/.3C
[Continuous CO_2 Laser - 500 Watts]
+ : conventionally heat-treated steel
● : .2"/sec, overlapping passes
✱ : .35"/sec, " "
☼ : .2"/sec, adjacent passes
× : .35"/sec, " "
Amount of Wear, volume : x10^4 cm^3
0
2
4
6
8
0
100
200
300
400
500
600
700
Slide Distance, metres
XBL 826-10345

Fig. 7a



XBL 826-10344

Fig. 7b

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720