THE JEWISH QUARTERLY REVIEW, XCII, Nos. 1–2 (July–October, 2001) 105–127

EARLY EVIDENCE FOR STEELMAKING IN THE JUDAIC SOURCES*

DAN LEVENE, Southampton University
BENO ROTHENBERG, The Institute for Archaeo-Metallurgical Studies at University College London

For Felix Posen Dr.h.c.
in friendship and gratitude

The discovery of steelmaking can be considered one of the important leaps in the evolution of homo faber. *Once iron smelting techniques were widely used, iron became the most common metal available. Although iron corrodes easily and is rather soft, with relatively simple skills and materials its surface can be "steeled" (carbon enriched) to produce a hard metal "case." The production of homogeneous steel by a more complicated technique was achieved in India and China a millennium before it was manufactured elsewhere. In those preceding years, "Indian steel" was known only as a traded commodity in the Near East.*

The present paper is the result of a working dialogue that has developed over the last few years between an archaeo-metallurgist and a philologist. Though the textual material is not generally concerned with conveying technological information, it inevitably reflects the realia of its own environment in both language and simile, if not always in the portrayal of significant political and commercial events. Our research shows that already in the Hebrew Bible, iron is portrayed as something more than just the common metal that it is, indicating an awareness of hardening and steeling techniques. In postbiblical literature, descriptive evidence of the processes of case hardening (carburization and quenching), the forge welding of steel tips, and the involvement of the Babylonian Jewish community in the trade of the highest quality Indian steel already in the 4th century CE *are identified. The juxtaposition of descriptions of technical processes, based on up-to-date archaeo-metallurgical scholarship, with textual references clarifies the metal-technological meaning of terms and descriptions used in the Judaic sources. The Judaic sources are here for the first time used as a source for*

*This research project is sponsored by Dr. Felix Posen, London, together with some initial support from the Israeli Ministry of Science, Jerusalem.

secular metal-historical studies; at the same time, especially due to comparisons with up-to-date archaeological data, these studies contribute to a better understanding of the often enigmatic Judaic texts.

In the Hebrew Bible (MT), copper, which was a prevalent metal, is mentioned much more frequently than iron. Both metals are referred to without much distinction as metaphors for strength and hardness. One might presume that any experience with case-hardened iron weapons, for which there is archaeological evidence dating at least as far back as the 10th century BCE, would have made it worthy of such a simile.[1] Yet, the fact that the language of the MT does not distinguish between carburized and plain iron means that we cannot be sure that it is really referred to in this manner. In what follows we investigate the Judaic sources against the background of iron technologies from the 12th century BCE to early medieval times.

1. IRON PRODUCTION

1.1 *Iron smelting*

According to the archaeological evidence available, the technique used in ancient times for the smelting of iron ore to metallic iron was the "bloomery process," named after the major smelting product of this process—the bloom—which was the raw material for iron and steel production.[2] The process involved is direct, one-step, solid

[1] T. S. Wheeler, J. D. Muhly, K. R. Maxwell-Hyslop, R. Maddin, "Iron at Taanach and Early Iron Metallurgy in the Eastern Mediterranean," *American Journal of Archaeology* 85 (1981), 245–268; B. Rothenberg and R. F. Tylecote, "A Unique Iron Smithy in the Northern Negev (Israel)," *Institute for Archaeo-Metallurgical Studies (IAMS) Newsletter* 17 (1991), 11–14 identified an Assyrian iron carburization smithy at Tel esh-Shari^{c}a, which is situated in the northwestern part of the Negev and has been identified with the biblical city of Ziklag (1 Sam 27:6–7).

[2] J. E. Rehder, *The Mastery and Uses of Fire in Antiquity* (Montreal, 2000), p. 123; W. Rostoker and B. Bronson, *Pre-Industrial Iron, Its Technology and Ethnology* (Philadelphia, 1990), pp. 89–97; R. F. Tylecote, "Furnaces, Crucibles, and Slag," in T. A. Wertime and J. D. Muhly (eds.), *The Coming of the Age of Iron* (New Haven, 1980), pp. 209–222; R. F. Tylecote, *The Early History of Metallurgy in Europe* (London, 1987), chap. 5; R. F. Tylecote, J. N. Austin, and A. E. Wraith, "The Mechanism of the Bloomery Process in Shaft Furnaces," *Journal of the Iron and Steel Institute* 209/5 (1971), 342–363.

state smelting of iron ore to metallic iron. Metallic iron, contrary to the smelting of ores of all other metals, never passed through a liquid state.

The operation of the bloomery furnace began by charging it with ore and fuel.[3] The common fuel for iron smelting was charcoal.[4] This furnace charge would then move slowly downward and gradually become hotter as it approached the combustion zone slightly above the level of the tuyere(s) (a nozzle through which air is forced into the furnace) or the flue (in the case of a natural, induced-draft furnace).[5] By the time it reached the combustion zone, the furnace charge had become a porous aggregate of particles of iron metal, unreduced silica, slag, and charcoal.[6] The reduced metal had the shape of tiny flakes of solid iron that, together with the fluid slag, sank down towards the bottom of the furnace. The heavy iron particles aggregated to a sponge-like, fairly heavy bloom and the liquid slag settled onto the furnace bottom ("furnace slag"). This slag was usually tapped out of the furnace ("tapped slag"), probably several times, in order to extend the smelting process and increase the size of the bloom. Finally, the furnace was left to cool down, in order to allow the removal of the bloom.

1.2 *Consolidating the bloom to solid iron ("bloom iron," "bar iron")*

The bloom from the smelting furnace was not solid enough to be forged directly into finished iron objects. It had to be further treated

[3] T. S. Wheeler and R. Maddin, "Metallurgy and Ancient Man," in T. A. Wertime and J. D. Muhly (eds.), *The Coming of the Age of Iron*, p. 115.

[4] Rehder, *The Mastery*, pp. 173–174; Tylecote, "Furnaces, Crucibles," p. 210; R. F. Tylecote, *Metallurgy in Archaeology; a Prehistory of Metallurgy in the British Isles* (London, 1962), p. 190.

[5] Because of a lack of archaeological evidence in the Near East, we do not know whether or when induced-draft furnaces were ever used in the region with which we are concerned. See Tylecote, "Furnaces, Crucibles," p. 210; J. C. Waldbaum, *From Bronze to Iron: The Transition from the Bronze Age to the Iron Age in the Eastern Mediterranean* (Göteborg, 1978), p. 59; T. S. Wheeler et al., "Iron at Taanach," pp. 260–261. Since the copper smelting furnaces of this period were all tapping furnaces, we may assume that the iron smelters knew the use of tapping. See B. Rothenberg, *The Ancient Metallurgy of Copper, Researches in the Arabah 1959–1984*, vol. 2 (London, 1990), chap. 1.

[6] Tylecote, *Metallurgy in Archaeology*, p. 186, fig. 44.

to be consolidated to malleable "bloom iron."[7] This could be done in an ordinary blacksmith's forge, i.e. a pile of charcoal and goatskin bellows protected by a tuyere, the like of which are still in use in many countries.[8] Although after reheating the bloom some of the slag became liquid and drained out of the bloom, most of the foreign inclusions had to be expelled by hammer blows. The first hammer blows were very rapid strokes with a slight hammer in order to weld together the separate flakes of metallic iron. This was followed by a repeated series of heating the bloom and heavy strokes with sledgehammers to squeeze out most of the occluded slag.[9] The scale of this consolidation is quite considerable, reducing the volume of the bloom by at least 50%.

By this treatment the flakes of iron are welded to one another and form a unified, solid mass of iron. In some cases where the bloom consisted of coherent iron, it could be forged in one piece. However, it was usually necessary to break up the bloom and separate the small pieces by hammering them into flat pieces of metal. There is some evidence that such pieces of iron were already considered to be a semi-finished product and traded over great distances.[10] To obtain larger pieces of iron or a shaped iron bar or plate these solid iron pieces had to be welded together by heating them in the forge, followed by hot hammering.

---

[7] In archaeo-metallurgical literature, "bloom iron," i.e., malleable, low carbon iron (less than 0.1% carbon), is often termed "wrought iron" because both have the same characteristics and are generally not distinguishable. However this latter term signifies a malleable, low carbon iron which, since the 19th century CE and until recently, was produced by the decarburization of cast iron, a process unknown in earlier times (except in China). We therefore use the term "bloom iron" for the consolidated primary product of the bloomery smelting process of iron (see W. Rostoker and B. Bronson, *Pre-Industrial Iron*, p. 139).

[8] D. H. Avry et al., "The Metallurgy of the Iron Bloomery in Africa," in R. Maddin, ed., *The Beginning of the Use of Metals and Alloys* (Cambridge, MA, 1986), pp. 266, 272, 281; R. Haaland, "Iron Production, its Socio-Cultural Context and Ecological Implications," in R. Haaland and P. Shinnie, eds., *African Iron Working, Ancient and Traditional* (Oslo, 1985), pp. 51–56; N. J. van der Merve and D. H. Avery, "Science and Magic in African Technology. Traditional Iron Smelting in Malawi," in R. Maddin, *The Beginning of the Use of Metals and Alloys*, p. 255; R. F. Tylecote, *A History of Metallurgy* (London, 1976), p. 42; Tylecote, *Metallurgy in Archaeology*, p. 193.

[9] Rostoker and Bronson, *Pre-Industrial Iron*, pp. 95–96; D. Strong and D. Brown, *Roman Crafts* (London, 1976), p. 147; Tylecote, *Metallurgy in Archaeology*, p. 186.

[10] Strong and Brown, *Roman Crafts*, figs. 229, 230, 259; Rostoker and Bronson, *Pre-Industrial Iron*, p. 96.

Raw blooms were normally consolidated to bloom iron (with a very low content of carbon and some slag inclusions) near the smelting site.[11] Once consolidated, the iron could be shaped by hammering into complex shapes, with repeated annealing to restore its ductility.[12] Much of ancient iron was traded in the shape of bars, plates or flattened balls. However, according to archaeological evidence, unworked raw blooms were also traded.[13] There is some evidence for the trading of small pieces of consolidated iron, most probably the small lumps of bloom iron that had not been welded into larger "bar iron."[14]

With the consolidation of the raw bloom into bars of bloom iron, the iron smelting process reached its conclusion and its product became the raw material for further treatment, i.e., steelmaking and/or forging into finished iron objects.

In the MT there are two terms that clearly distinguish particular types of iron: *barzel ᶜashot* ברזל עשות (Ezek 27:19) and *barzel mi-ṣafon* ברזל מצפון (Jer 15:12). *Barzel ᶜashot* is mentioned in Ezekiel as a commodity that was brought to the wealthy city of Tyre. The word *ᶜashot* is an hapax legomenon for which there is no certain etymology; the best suggestion, on the basis of archaeo-metallurgical knowledge, would be "consolidated bloom iron."[15] The Greek, Aramaic and Syriac translations of the MT express, in their interpretation of this unique term, material realities appropriate to their own times. In the LXX, the translation for *barzel ᶜashot* is σίδηρος εἰργασμένος ("worked iron"); in the Peshita it is *parzela detpalḥyn* (ܦܪܙܠܐ ܕܐܬܦܠܚܝܢ),

[11] P. R. S. Moorey, *Ancient Mesopotamian Materials and Industries: The Material Evidence* (Oxford, 1994), pp. 282–283; Rostoker and Bronson, *Pre-Industrial Iron*, p. 96.

[12] Annealing, i.e., heating the iron to temperatures well below its melting point of about 1500°C, softened the iron and restored its essential ductility. The optimal annealing temperature of iron would have been c. 400°C.

[13] Moorey, *Ancient Mesopotamian Materials*, p. 290.

[14] "Bar iron," a low carbon forgeable metal and the end product of the consolidation of raw iron from the bloomery process, was often marketed in different, convenient shapes. By the 8th century BCE some were even used as currency bars. See G. Jacobi, *Werkzeug und Gerät aus dem Oppodum von Manching* (Wiesbaden, 1974), pp. 248–253, plates 76–77; Moorey, *Ancient Mesopotamian Materials*, p. 283; Rostoker and Bronson, *Pre-Industrial Iron*, p. 96; Tylecote, *The Early History*, pp. 253–258; Tylecote, *A History of Metallurgy*, pp. 40–41, fig. 30.

[15] *ᶜEshet* עשת vb. be smooth or shiny (?); n. plate (?). See F. Brown, S. R. Driver, and C. A. Briggs, *A Hebrew and English Lexicon of the Old Testament*, 3rd ed. (Oxford, 1957), p. 799b. See also L. Koehler and W. Baumgartner, *The Hebrew and Aramaic Lexicon of the Old Testament* (Leiden, 1995), p. 896a for an understanding of עשות, on the basis of the LXX, as "worked" or "treated."

"iron that you will work").[16] It is possible that both read *ᶜśwt* as the infinitive of the verb עשׂה "to make," rather than *ᶜšwt*. The verb עשׂה is commonly used in the MT to denote any number of techniques of fabrication for a variety of materials. It is frequently associated with metals, iron among them.[17] *Barzel ᶜśot* (עשׂוֹת), literally "making," "working," or "workable iron," are all accurate descriptions of the only type of iron that would have been available.[18]

A similar form to that which appears in Ezek 27:19, which is, however, with a *sin* rather than a *shin*, does exist in Ezek 23:21, בַּעֲשׂוֹת;[19] this term means 'squeezed' or 'pressed'. If ברזל עשות be read with a *sin* rather than a *shin*, as we have suggested, then the understanding of our term as 'squeezed' or 'pressed iron' would be also consistent with what we now call "consolidated bloom iron." It might be further noted that בַּעֲשׂוֹת, in Ezek 23:21, is translated in the LXX as ἐποίεις, an imperfect form of ποιέω. This word is similar in meaning to the term used in the LXX for עשות in Ezek 27:19, which is a form of the word ἐργάζομαι, both words can mean 'to work' and are also both used in the LXX for the Hebrew verb עשׂה.[20]

Targum Jonathan interpreted *barzel ᶜashot* as *beᶜarqyn debarzel* (בערקין דברזל, "rods of iron").[21] It seems that in this case the translator understood *ᶜashot* in relation to עשת, another hapax legomenon (Song 5:14), which is thought to mean "plate" or "lump."[22] This would be a realistic description not of the type of iron, as in the

---

[16] In Syriac, the passive participle of the peᶜal of the verb *plḥ* can have the sense of "wrought." Otherwise both the peᶜal and paᶜel can mean "to work." See J. Payne-Smith, *A Compendious Syriac Dictionary* (Oxford, 1957), pp. 447b–448a.

[17] 1 Kgs 22:1 ויעש לו צדקיה בן כנעניה קרני ברזל, Jer 28:13 ועשית תחתיהן מטות ברזל.

[18] Cf. David J. A. Clines, ed., *The Dictionary of Classical Hebrew* (Sheffield, 1995), 2:261b, in which an emendation to עֲשׂוּת* (which in our case would be עֲשׂוּת*) is suggested. In this case our verb would be a passive participle.

[19] Read בְּעַשּׂוֹת; see Brown, Driver, Briggs, p. 796a and Koehler-Baumgartner, p. 892a.

[20] G. Abbott-Smith, *A Manual Lexicon of the New Testament* (Edinburgh, 1937), pp. 178 and 369. We would like to thank David Goldenberg for suggesting we examine Ezek 23:21 for a connection with our term and Carol Downer for her help with Greek terms.

[21] J. Levy, *Chaldäisches Wörterbuch über die Targumim und einen grossen Theil des rabbinischen Schriftums* (Leipzig, 1881), 2:247b.

[22] Brown, Driver, Briggs, *Lexicon*, p. 799b (cf. Koehler-Baumgartner, p. 898b). In the commentary of R. David Kimḥi (12th–13th centuries) the association between עשות and עשת is also made.

LXX and Peshita, but of the bar shape in which consolidated bloom iron is known to have been traded in antiquity.

The commentary on the order of Toharot, attributed to Hai Gaon, cites both ברזל עשות (Ezek 27:19) and בערקין דברזל (Targum Jonathan) in its interpretation of the mishnaic עשת (mKel 11.3), which it explains as meaning "a big piece of iron."[23] In his commentary on the Mishna, Maimonides also equated the mishnaic עשת with the biblical ברזל עשות. Since Epstein has argued convincingly that Maimonides consulted the gaonic commentary, it might be suggested that it was the origin of this particular association of terms in Maimonides' commentary.[24] However, Maimonides went beyond the purely lexical and added a rather detailed metallurgical description to illustrate his understanding of these terms:

> עשת is an iron lump at the time of its extraction from the ore of the mine—and [it is] from this [same term that we have] ברזל עשות (Ezek 27:19)—prior to its refinement by a process of being melted several times, when it [the עשת] is hammered [repeatedly] until there become separated from it many substances which are clinging to it from the mine, as it is known among the artisans.[25]

This description of the bloomery process shows that Maimonides had either witnessed the process himself or had made some inquiries among "the artisans" in order to clarify the details of this process. It must be noted, however, that עשת is not associated only with iron; it can also mean a lump of any metal.[26]

The terms עשות (ברזל) (Ezek 27:19), עשת (mKel 11.3) and עששיות (של ברזל) (bYom 34b, bAZ16a, bSan 108b and GenR 93.6) have been associated with each other by medieval commentators. In the gaonic commentary on Toharot, the biblical term ברזל עשות is used to explain

---

[23] J. N. Epstein, *The Gaonic Commentary on the Order of Toharot Attributed to Hay Gaon* (Jerusalem, 1981), p. 20.

[24] Epstein, *The Gaonic Commentary*, pp. קיד-קיט.

[25] J. Qafiḥ, *Mishna, ᶜim Perush Rabbenu Moshe Ben Maimon, Maqor we-Targum* (Jerusalem, 1968), 1:115. The description "a process of being melted several times" should be changed into "a process of being heated several times," since no melting of iron would have been practiced or possible at the time of Maimonides. In addition, repeated heating of the iron in a smithy would have been metallurgically the appropriate technique.

[26] Cf. bMen 28a מנורה היתה באה מן העשת ומן הזהב "The candlestick had to be made from one mass and of gold"; חצוצרות היו באים מן העשת מן הכסף "The trumpets had to be made [each] from one mass and of silver."

the Mishnaic עשת.[27] The meaning of עשת is not entirely clear. David Kimḥi (to Ezek 27:19) associates it with Song 5:14, where the same term (עשת) occurs, even though in that verse it refers to ivory rather than metal. On the basis of the context in that verse, it has been tentatively understood to mean "smooth," "shiny," "worked," or "treated."[28] Rashi to Song 5:14 explains עשת to mean some kind of lump or mass of material. He clarifies this somewhat in his commentary to bYom 34b, where he explains (של ברזל) עששיות by way of that same verse, stating that עששיות are "thick pieces."[29] The three terms, עשת ,עשות and עששיות are all rare, and it seems that there is a circular pattern in the commentaries, whereby each is explained by citing at least one of the others. We might note, however, that whereas עשות and עשת are derived from the root עשת, עששיות is derived from the root עשש.[30] Unlike עשת, the term עששיות appears with no other metal but iron, and only in the plural form of the noun. It occurs in four places: bYom 34b, bAZ 16a, bSan 108b and GenR 93.6. In bYom 34b the lumps of iron are referred to as עששיות both before and after they are heated on a charcoal fire, therefore not distinguishing the change in the quality of the iron which occurred during that time. In bAZ 16a the "lumps of iron" (עששיות) are distinguished from the "Indian iron" which was of a special weapon-making quality.[31] In GenR 93.6 there is no mention of the quality of the "lumps of iron" at all; yet the narrative specifies that in this case the lumps were big enough to put in the mouth.[32] This implies that the עששיות were quite small, a reading that coincides with the diminutive force of this form of noun.[33]

It seems quite clear that these three terms have similar meanings. However, one must bear in mind that there are differences between

---

[27] The biblical עשות is a *qăṭâl* form that is based on the infinitive absolute and represents the abstract idea of the verb. See A. E. Cowly, *Gesenius' Hebrew Grammar, as Edited and Enlarged by the Late E. Katzuch* (Oxford, 1963), p. 231. The Mishnaic עשת is a *qaṭl* form that is derived from the simple stem of a strong verb. See M. H. Segal, *A Grammar of Mishnaic Hebrew* (Oxford, 1927), p. 99.

[28] Brown, Driver, Briggs, *Lexicon*, p. 799b and Koehler-Baumgartner, p. 896a.

[29] See also Rashi's commentary to עששיות in bAZ 16a.

[30] See n. 27. The noun עששית is formed with the feminine ית suffix and has a diminutive force. See Segal, *A Grammar*, p. 121.

[31] Both bYom 34b and bAZ 16a are discussed in detail below.

[32] בשעה שהיה יהודה מעלה חמה . . . היה נותן עששיות של ברזל לתוך פיו ומוציאן כאבק "When Yehudah would get angry . . . he would put lumps of iron into his mouth and spit them out as dust."

[33] See n. 30 above.

them. It is possible, as the medieval tradition suggests, that these terms are lexically connected. Yet, the disparity in time between the Hebrew of the Bible and that of the Mishna and the Baraitot, in which these three terms are so poorly represented, makes it difficult to accept with any confidence a common lexical origin for these three terms.

Jer 15:12 reads, "Will iron break iron from *ṣafon* (literally "north") and copper/bronze?"[34] Apart from meaning "north," *ṣafon* is also a place-name. Both Pritchard and Tubb, who excavated around Tell es-Saᶜidiyeh in the Jordan valley, the largest site in an area for which there is an attested history of copper-based metal work from the late Bronze Age into Iron I (between the 13th and 10th century BCE), considered the possibility of identifying it with the biblical *Ṣafon*.[35] From excavations of the sites in the region, the graves in Tell es-Saᶜidiyeh stood out for having yielded a greater number of finds of small iron objects such as daggers, knives, arrowheads and bangles, as well as the copper and bronze objects that are typical of other local sites. It might well be that Jer 15:12 is a testament to *Ṣafon*'s reputation as makers of superior iron products, not necessarily iron smelting from ore.

As we shall show, developments in iron technology are well attested in postbiblical Jewish literature. There are a number of references that testify to knowledge of the technique of case hardening by carburization and quenching as well as one clear reference to steel. It must be noted that none of the literature that is cited was composed with the intention of being, or indeed incorporating, anything that resembles a technical manual. Any discussion of metallurgical issues

[34] In the MT there is no general term for bronze; only copper is named. Still, we know that much of what is called *neḥoshet* was indeed, at that time, some type of bronze or even brass. Obviously, here we may assume that bronze is meant because copper is rather soft and a metal harder than iron is indicated.

[35] J. D. Pritchard, *Tell es-Saᶜidiyeh Excavations on the Tell 1964–1966* (Philadelphia, 1985), pp. 2–3; J. N. Tubb, "The Role of the Sea Peoples in the Bronze Industry of Palestine/Transjordan in the Late Bronze–Early Iron Transition," in J. Curtis, ed., *Bronzeworking Centres of Western Asia c. 1000–539 B.C.* (London, 1988), p. 260; J. N. Tubb, "Sea Peoples in the Jordan Valley," in E. Oren, ed., *The Sea Peoples and Their World: A Reassessment* (Philadelphia, 2000), pp. 919–913. See also B. Rothenberg, "Who were the 'Midianite' Copper Miners of the Arabah?," in T. Rehren et al., eds., *Metallurgica Antiqua: In Honour of Hans-Gert Bachmann and Robert Maddin* (Bochum, 1998), pp. 197–212.

was preserved as a by-product of other issues, such as religious law and aggadic narrative.

The appearance of technological knowledge in these texts need not surprise us, as we know that many of the rabbis had to earn their living by common means and that there were among them skilled craftsmen.[36] Rabbi Johanan, a 3rd-century CE tanna, is repeatedly referred to in the Talmud as "the son of the blacksmith" in reference to his father Isaac "the blacksmith." Another famous second-generation tanna who was a blacksmith was R. Joshua (2nd century CE). It is said that the walls of his house, which also served as his workshop, were blackened from the soot of the charcoal.[37]

2. STEELMAKING

Steel is essentially an iron-carbon alloy with a carbon content of 0.1 to 1.8%. In ancient times, there was no intentional direct production of steel; the carbon content of ancient bloom iron was normally well below 0.1%. However, already early in the 10th century BCE, mild steel was produced in the Eastern Mediterranean by indirect techniques, based on the intentional increase of the carbon content, a process called "carburization."[38]

Archaeo-metallurgical literature lists three different technologies for steelmaking:[39] Augmenting the carbon contents of iron (1) by cementation, i.e., by the reaction of iron with gaseous carbon; (2) by melting a mixture of bloom iron and charcoal (or other kinds of solid carbon) in a crucible ("crucible steel"); (3) by fusion, i.e., heating together bloom iron and high-carbon cast iron. Since the first two techniques of carburization are relevant for our present investigation, they will be discussed in some detail.

---

[36] Maimonides considered it important to remind his readers that many of the greatest sages had to earn their living as artisans, among whom were also blacksmiths (*Mishne Torah*, Hilkhot Matanot ᶜAniyim 10.18).

[37] bBer 28a.

[38] In Israel at Taanach, Hazorea, Tell el-Farah South. See Wheeler et al., "Iron at Taanach," pp. 245, 263; Wheeler and Maddin, "Metallurgy and Ancient Man," pp. 121–124.

[39] J. Merkel, A. Feuerbach, D. Griffiths, "Analytical Investigation of Crucible Steel Production at Merv, Turkmenistan," *IAMS Newsletter* 19 (1995) 12–14; Rostoker and Bronson, *Pre-Industrial Iron*, chap. 11.

Carburization on its own did not produce homogeneous steel, but only produced a thin layer of iron-carbon alloy on the surface of the treated iron object, i.e., its "case" (hence "case hardening"). This would have produced a noticeable hardening of the surface layer and the iron object could be worked like a mild steel. However, carburization as such did not produce hard steel, and for more effective hardening either cold working or a specific additional heat treatment called "quenching" (see below) was required.[40]

2.1 *Carburization in an open furnace*

Carburization in an open furnace was probably the earliest steelmaking technique.[41] The early smith seemingly understood that by leaving a lump of consolidated bloom iron, or a semi-forged bloom iron object in a pile of glowing charcoal, he could change the character of the iron and make it forgeable into a much harder and sharper tool. The chemistry of this technique of steelmaking (called "cementation"), which was never understood as such by the ancient smith, involved the absorption of carbon monoxide, produced in the glowing charcoal pile, by the iron object heated to a temperature above 723°C.[42] It may not have taken too long for the smith to realize that much higher temperatures, such 910°C and above (recognizable by the color of the glow), would produce a much better steel. However, it is important to mention that this carburization process in an open forge could only carburize a thin surface layer of the object, i.e., its "case," while the core of the iron object was much less affected, if at all. Unless the carburization process is carried on for many days and at a very high temperature (above 950°C)—extremely difficult in an open forge—less than one millimeter of steel will be produced as an outer case of the object. However, such a hard case would have been quite adequate for a sharp cutting edge or piercing point—and the evidence clearly confirms the widespread use of this case hardening technique.[43]

[40] Cold working, i.e., shaping the iron by hammering at normal temperature, involved stretching, bending, twisting and drawing (to make wire).

[41] H. H. Coghlan, *Notes on Prehistoric and Early Iron in the Old World* (Oxford, 1956), chap. 7; Rostocker and Bronson, *Pre-Industrial Iron*, p. 122.

[42] Coghlan, *Notes on Prehistoric and Early Iron*, pp. 58–60.

[43] This technique was widely used from the beginning of the Iron Age to the mid-19th century CE. See Rostoker and Bronson, *Pre-Industrial Iron*, p. 122.

2.2 *Carburization in a closed furnace*

To overcome the problem of maintaining carburizing conditions in an open furnace, to facilitate deeper carbon penetration, and to produce a steel of more even hardness, the ancient smith realized, even in the later Iron Age, the need for a closed carburization furnace. Archaeological evidence for this important technological advance has been found in the Assyrian citadel of the 7th–6th century BCE, at Tel esh-Shari^{c}a, in the Northern Negev.[44] The furnace excavated in the courtyard of the citadel has an arched top and its two tuyeres were situated in such a way that much of the furnace was not in the direct line of the air stream from the bellows. It was evident that long iron objects had been packed in charcoal, away from the fire, and heated for a considerable time—evidently for a protracted carburization process. Some such iron objects were indeed found next to the furnace.

This "pack carburizing" technology, also called "box hardening," was used in different variations in many parts of the world even up to the late 19th century CE. Fundamentally, the carburization process, both in an open and closed furnace or vessel, remained throughout only a process of "case hardening" of varying depths, hardly ever producing a really homogeneous steel. To achieve such homogeneous results, other technologies were required: pile welding, piling and folding and, most important, Indian crucible steelmaking.

2.3 *Heating, quenching and tempering*

The technique of hardening steel by heat treatment is a three-step process: heating, quenching and tempering. After the semi-forged steel object has been heated to a red-orange glow (723° to 850°C, depending on the carbon contents), it is quenched by quick immersion in cold water. Since the high cooling rate (400° to 600°C within two minutes) required for effective hardening occurs solely on the surface of the quenched object, only a thin surface layer will be of maximum hardness. Quenching can nevertheless cause the steel object to become rather brittle and hence unsuitable for heavy use. It is therefore necessary to temper the steel by reheating the object to a temperature between 100° and 650°C, well below the initial forging

---

[44] Rothenberg and Tylecote, "A Unique Iron Smithy," pp. 11–14.

temperature. Tempering softens the metal and at the same time increases its toughness; but even so, the metal remains hard enough to cut other metals.

The advantage of heat treatment of low carbon steel is that tempering levels can be controlled by observing the color of the heating glow. This enables the smith to choose the degree of hardness, strength and toughness, with ductility best suited for the job at hand. Another advantage of heat treatment is that steel objects of variable sizes and shapes can be hardened, in contrast to cold working, which can only be applied to thin and small objects. Furthermore, this process is repeatable in case the results of the first treatment are not satisfactory.

Archaeological evidence has shown that both carburization and quenching were used fairly early in the Early Iron Age all over the Old World, and there were several methods to deal with the brittleness of case-hardened tools, induced by quenching in cold water.[45] Recent archaeo-metallurgical investigations of iron finds from Israel, Egypt, and Cyprus provide clear evidence that complete manipulation of iron—carburization, quenching and tempering—was already in use in the Early Iron Age (Israel 12th–11th century BCE, Cyprus 11th century BCE, Egypt ca. 900 BCE).[46]

Other techniques were also employed to deal with the brittleness of quenched carburized iron, one of which was "interrupted quenching," that is, the quick withdrawal of the hot steel object from the quenching bath while still hot and allowing it to cool down slowly at room temperature, producing a much tougher and a less hard "case."[47] There was also the possibility of the intentional use of steel with a low carbon content (0.1–0.2%) by controlling the carburization process.

[45] Wheeler and Maddin, "Metallurgy and Ancient Man," pp. 121–123.

[46] R. Maddin, "Early Iron Technology in Cyprus," in J. D. Muhly et al., *Early Metallurgy in Cyprus, 4000–500 B.C.* (Nicosia: 1982), pp. 305–306; A. M. Snodgrass, "Iron and Early Metallurgy in the Mediterranean," in T. A. Wertime and J. D. Muhly, eds., *The Coming of Steel*, p. 341; Tylecote, *A History of Metallurgy*, p. 45. Due to the lack of systematic metallographic investigations of ancient iron, there is very little certain evidence for the tempering of late Iron Age to early Islamic iron; but we may assume that this technique, clearly evidenced in the region in the early Iron Age, was known throughout the region in later times.

[47] Rostoker and Bronson, *Pre-Industrial Iron*, p. 15; T. A. Wertime, *The Coming of Steel* (Chicago, 1962), p. 18.

Obviously the latter would be the outcome of practical experience rather than understanding the chemistry/mineralogy involved.

2.4 *Pile welding, piling and folding*

To overcome the limitations of the case-hardening technique, which only affected the surface layer of the iron, the ancient smith would sometimes weld together several case-hardened iron pieces to produce composite layers of alternating low and high carbon iron, thus creating a metal with greatly increased elasticity. Such metal was in great demand for the forging of swords and the like. This technique is called "pile welding."[48]

The early smith also used another, similar technique to produce more homogeneous carburized iron, termed "piling and folding."[49] A lump of bloom iron was forged into a thin sheet, which was carburized on one or both sides and then folded over to sandwich the high carbon parts between the low ones. Subsequent heating diffused the carbon more uniformly throughout the metal, resulting in a lump of quite homogeneous mild steel.

Iron that prevails over iron, פרזלא דשליט בפרזלא

An aggadic tale (bSan 96b) relates a tradition about Nebuchadnezzar, the Babylonian king who sacked Jerusalem at the beginning of the 6th century BCE. It is told that he sent his deputy Nebuzaradan "three hundred mules laden with axes of iron that prevails over iron (פרזלא דשליט בפרזלא)" to help him breach the gates of Jerusalem. Considering the Assyrian (6th century BCE) smithy from Tel esh-Shari^c^a, in the northwestern Negev of Israel, identified by Rothenberg and Tylecote as being used specifically for the carburization of iron weapons, this story documents that the steeling of iron, in use already in biblical times, was still in common usage about a thousand years later at the time of the Talmud.[50]

---

[48] Coghlan, *Notes on Prehistoric and Early Iron*, pp. 152–153.

[49] Rostoker and Bronson, *Pre-Industrial Iron*, p. 132; Tylecote, *The Early History*, p. 259.

[50] See above n. 42. The Babylonian Talmud was probably redacted at some time between the 5th and 7th centuries CE.

Isṭemaʾ, אסטמא

In bBer 62b there is a statement that, on first reading, appears to be somewhat enigmatic: "R. Shmuʾel[51] said: passing water at dawn is like *isṭemaʾ* (אסטמא) to iron, defecation at dawn is like *isṭemaʾ* to iron."[52] The word *isṭemaʾ* is a loan-word from the Greek στόμωμα, which means 'hardened iron so as to take a hard edge,'[53] that is, carburized iron that has been heated and quenched in water. An allusion to case hardening made by the very same Shmuʾel clarifies the association with health: "If one bathes in hot water and does not rinse himself in cold water, he is like iron put into the fire but not into cold water" (bShab 41a). Obviously, this is clear evidence of an accurate understanding of the process of hardening carburized iron by quenching, a metallurgical understanding possibly derived from the Hellenistic cultural sphere from which the terminology was adopted.[54]

Ṣaraf, צרף

In the previous passage we noted that there was an awareness of hardening carburized iron by quenching, but did not discuss any possible awareness of the process of carburization itself. In bYom 34b there is a discussion which relates that, on the eve of the Day of Atonement, it was customary to prepare a charcoal burner in which iron lumps (עששיות של ברזל) were heated. On the following day, these were removed from the charcoal and dropped into a bath of water so that the old priest would not have to suffer a chill from the cold water. R. Judah[55] recognized that the iron was altered after it was heated on charcoal (i.e., carburized) and that when it came into contact with the

---

[51] Babylon, 3rd century CE.

[52] MS Paris 671 סטומא.

[53] H. G. Liddell and R. Scott, *A Greek-English Lexicon*, revised by S. H. Jones and R. McKenzie, with a supplement (Oxford, 1968).

[54] There are a number of reasons to suggest that the origin of Shmuʾel's statement derives from the western sphere. The most compelling is the fact that it is delivered in Hebrew with Greek terminology. Furthermore, the fact that Shmuʾel was Babylonian himself does not exclude the possibility that he had some knowledge and understanding of the Hellenistic sphere, as the Talmud suggests that he also studied under Palestinian-born teachers such as Levi b. Sisi (bShab 108b) and even visited Yehuda ha-Nasi (bBM 85b).

[55] A second-generation Babylonian tanna who lived in the 2nd century CE.

water (i.e., quenched), it would acquire hardness (צירוף). He was concerned, therefore, that quenching, as the end of this two-step process and applied to the carburized iron lumps on the Day of Atonement, would constitute an act of work—an infringement of the holy day.

In bBM 84a a debate is recorded between R. Johanan and his contemporary Resh Lakish about what would be considered the final stage in the manufacture of a sword, knife, dagger, spear, hand-saw or scythe:

> רבי יוחנן אומר משיצרפם בכבשן ריש לקיש אמר משיצחצחן במים
>
> R. Johanan ruled: When he hardens them in a furnace, Resh Lakish maintained; When he puts them in water.[56]

We propose the following understanding of this passage: R. Johanan, "the son of a smith," often witnessed the making of iron tools, which ended with prolonged heating in the furnace. These tools would have acquired a noticeable hardening of the surface, that is, case hardening by carburization. Resh Lakish, on the other hand, whose early experiences as a gladiator had acquainted him with the use of weapons, would have known that a good sword or dagger needed quenching after carburization as the final step, to assure a hard cutting edge.[57]

In both bYom 34b and bBM 84a, the same root (צרף), is used with the meaning "to harden," in the first instance by means of "cold water quenching" and in the second with "carburizing." In the Talmud there are no specific words for the processes of carburization and quenching, the formal understanding of which are the products of modern science. Rather, the language is more descriptive: related to heating—מחמין (bYom 34b); coming in contact with cold water—מטילין לתוך הצונן (bYom 34b) and יצחצחן במים (bBM 84a); and of course hardening—מצרף and צירוף (bYom 34b) and יצרפם (bBM 84a). Nevertheless, both passages conclusively illustrate an understanding that a two-stage process was involved in hardening the surface of iron and trans-

---

[56] The word צחצות is attested in a variety of meanings including "to dilute," "to polish," "to clarify" and specifically with swords, "to brandish." See M. Jastrow, *A Dictionary of the Targumin, the Talmud Babli and Yerushalmi and the Midrashic Literature* (Jerusalem, 1950), pp. 1273b, 1274a. In this case, the only metallurgical interpretation which makes sense is "to quench" or more literally, "to come in contact with cold water."

[57] bGit 47a. See M. Margaliyot, *Enşiklopedia le-Ḥakhme ha-Talmud weha-Ge᾿onim*, ed. Y. Eisenberg (Tel Aviv, 1995), 2:318.

forming it into steel: heating in a charcoal fire, i.e., carburization, and plunging heated (carburized) iron into water, i.e., quenching.

2.5 *Steel-to-iron forge welding*

At least as early as the middle of the first millennium BCE, a new technique was used for the manufacture of cutting tools and weapons.[58] This consisted of forge welding a cutting edge of hard, high-carbon steel onto the body of the object made of soft bloom iron. In other words, the production of a composite of iron and steel, instead of either the use of homogeneous steel or direct case hardening (carburization and quenching) of the forged iron object, which in most cases produced only a very thin cutting edge. Steel-to-iron forge welding had the additional benefit of producing a cutting edge that was better able to withstand repeated sharpening, although even the steel-iron composition will ultimately lose its hard cutting edge—and usefulness—through repeated resharpening. The steel for the cutting edge either could have been imported "Indian iron" or was locally produced by one of the techniques of carburization discussed above.[59]

Ḥisum, חסום

The forge welding of a lump of steeled iron to create a sharp working edge for a tool is specified already in the Mishna. The term used for this kind of edge is *ḥisum* חסום, literally a "block" or "muzzle." An adze, chisel, plane, or drill are all tools that are mentioned in mKel 13.4 as having such an edge. The same mishna states that if "their steeled edge was removed they would not be susceptible to impurity," meaning that they have been rendered useless.[60] In tKel BM 1.3 and 3.7, a pickaxe is also described as having a steeled edge.

The medieval commentaries on this mishna are particularly rich in descriptions and terminology. The gaonic commentary, considered to be a compilation dating from the 10th century, describes *ḥisum* as

[58] Rostoker and Bronson, *Pre-Industrial Iron*, pp. 169–170; Wheeler and Maddin, "Metallurgy and Ancient Man," figs. 4, 14 demonstrate this technique.

[59] See also below, sec. 3.

[60] A utensil in a functional state of manufacture or repair is considered to be susceptible to impurity. However, if it is not completely manufactured or has been damaged to such a degree that it can no longer perform its function, it is considered unsusceptible to impurity.

the addition of "good iron" for the sharp edge of the tool.[61] In this commentary we are told that "good iron" is, in Arabic, *fulad* פולד (steel) though another gaonic text refers to it as *shaburqan* שאבורקאן.[62]

Maimonides includes a fuller description in his commentary to this mishna:

> And the meaning of "they were damaged" is *tathlamat* (תת'למת—Arabic from the root *thalama* "broken off edge") . . . as the edges of all these utensils (the adze, chisel, plane, and drill) are as those of knives. And regarding all these utensils, and their like amongst the big iron tools, the whole of the body of the tool is from soft iron, whereas, the edge of the tool alone—with which one cuts or perforates or smoothes—is made of steel (פולד). This is the iron that is processed by a particular expertise until it is made stronger and harder than other iron, and is known amongst us by name as "Indian Iron." This action is called by the smiths *altalqim* (אלתלקים—Arabic from *laqama* "morsel"), namely, the joining of the steel (פולד) to the soft [iron]. And that steeled iron (אלחדיד אלפולד) edge which they sharpen and harden in water (quenching), as is well known amongst the artisans, is called *ḥisum* (חסום) on account of the fact that it is on the edge (literally "mouth") of the tool, strengthening it, slowing and prohibiting it from twisting and bending. As it is said: "You shall not muzzle an ox while it is threshing" (Deut 25:4)[63] . . . Here [in the mishna] they said, "their *ḥisum* was removed"—meaning to say that that hard and quenched edge called "the morsel" (אללקמה) became removed.

Maimonides' description of this edge as made from an iron which acquired its qualities for hardening by "being processed by a particular expertise" is a clear indication of domestic, North African production of a mild steel in the mid 12th century CE.

3. INDIAN CRUCIBLE STEEL OR WOOTZ

Wootz (a term of uncertain etymology) is an exceptionally homogeneous iron-carbon alloy containing more than 1.5% carbon. The origins of this technology are not clear although it seems certain that

[61] Epstein, *The Gaonic Commentary*, pp. 30–31.

[62] Ibid., p. 31, n. 15: "*Shaburqan* appears to be used in specific instances to mean meteorite iron, and in other instances to mean cast iron, but that very often it can only be understood as a hard variety of iron." See also J. W. Allan, *Persian Metal Technology 700–1300 AD* (Oxford, 1979), p. 74.

[63] The muzzle of the ox is used as a metaphor for the steeled edge of the tool.

it was first invented and developed in India. Already in the first millennium CE, wootz was exported in large quantities from India to the West, and before that to the Mediterranean region as well.[64] Unfortunately, due to the lack of archaeological excavation and analytical research on early iron objects, there is very little material evidence for Indian steel.[65] Likewise, there is no archaeological evidence for its importation and usage in our region, forcing us to revert to literary documentation.[66]

Basically, Indian steelmaking was a high temperature carburization-crucible-melting process.[67] The crucibles were of conical shape, 10–20 centimeters high, and had a diameter of only 5–6 centimeters. Since the temperature needed in this process was at least 1400°C, specially prepared, highly refractory clays were necessary for the manufacture of the crucibles. The furnaces were either small and simple fire-pits, enough for a small number of crucibles; or proper, stone-built, dome-shaped installations that could contain a large number of crucibles in each furnace operation.

Well-consolidated bloom iron was used as raw material, broken into very small lumps to fit into the crucible. Charcoal and/or wood (and, according to some reports, also some green leaves) were packed into the crucible to provide carbon.[68] After charging, the crucibles were sealed with a lump of wet clay or a lid. Five to fifty such crucibles were stacked in rows or in a pile, separated from the combustion chamber or fire-pit below or in front. The furnace was then loaded with charcoal as fuel; the air blast was provided by bellows. As the heat increased, the iron in the crucibles underwent carburization of more than 1.5% carbon. When the temperature rose above the liquidus for such carbon-iron alloy, it melted and formed a fully fused, homogeneous lump of steel, shaped like the crucible in which it was made.[69] To reach such a superior product, the wootz makers

---

[64] Rostoker and Bronson, *Pre-Industrial Iron*, p. 127.

[65] R. F. Tylecote, "Early Metallurgy in India," in *The Metallurgist and Materials Technologist* (Accrington, Eng., 1984), pp. 346–347.

[66] B. Bronson, "The Making and Selling of Wootz, a Crucible Steel of India," *Archaeomaterials* 1 (1986) 17–21.

[67] Ibid., chap. 8: Tylecote, *Metallurgy in Archaeology*, p. 294; Tylecote, *Early Metallurgy*, pp. 346–347.

[68] J. Percy, *Metallurgy, Iron, Steel* (London, 1864), pp. 773–775; Rostoker and Bronson, *Pre-Industrial Iron*, p. 128.

[69] B. Prakash, "Metallurgical Study of Ancient Swords," in V. Tripathi, ed., *Archaeometallurgy in India* (Delhi, 1998), pp. 64–80.

had to ensure the complete liquidation of the steel by proper control of the air blast. The whole operation of such a large furnace required nine to ten hours.

Wootz is a homogeneous high carbon steel that can be forged. But to achieve this, it first has to be annealed. As we know from Indian sources, such annealing took place immediately after the production of the wootz. The exported wootz reached its destination already annealed and ready for forging.[70]

Indian steel, easily recognizable because of its conical shape, was traded all over the ancient world and was mainly used for the production of sword blades.[71] Many of these blades were intentionally treated to show a special "fish roe" texture, known as a "damascene" pattern.[72] Early on, Damascus became an important trading and working center for Indian steel and sword blades, and its name signified until modern times a very high-quality steel originating from India. Indian steel is known to have been imported into the Middle East as raw material for weapons, and in the late first millennium CE it was already manufactured by local forges, next to ordinary iron and low grade carbon-steel.[73]

Parzelah hindu^ɔah, פרזלא הינדואה

In bAZ 16a there is a clear reference to the trade in steel:

> אמר רב אדא בר אהבה אין מוכרין להן עששיות של ברזל מ״ט משום דחלשי מינייהו כלי זיין אי הכי אפילו מרי וחציני נמי אמר רב זביד בפרזלא הינדואה והאידנא דקא מזבנינן א״ר אשי לפרסאי דמגנו עילוון:
>
> R. Adda b. Ahabah said: One may not sell them [non-Jews] lumps of iron. Why? Because they may forge weapons out of them. If so, spades and pick-axes should also [be forbidden]!—R. Zebid said: [What is specifically meant is] Indian iron (*parzelah hindu*ɔ*ah*). And why then are we selling it?—R. Ashi said: [We sell it] to the Persians who protect us.[74]

The Indian iron of weapon-making quality mentioned here is most likely what archaeo-metallurgists refer to as Indian crucible steel or

---

[70] Rostoker and Bronson, *Pre-Industrial Iron*, p. 129.

[71] Tylecote, *Early Metallurgy*, pl. 10.

[72] Rostoker and Bronson, *Pre-Industrial Iron*, chap. 11, paragraph 8.

[73] Ibid., p. 127, n. 4.

[74] R. Adda was a Babylonian amora of the 3rd century. R. Zebid, also from Babylon, lived in the late 4th century CE, and R. Ashi was a sixth-generation Babylonian amora (352–427).

wootz. This reference is the earliest description of trade in this high-quality steel from the east westwards. It also identifies the local Jewish community as active partners in the iron trade. Important documentation, dating to the 11th–12th centuries CE, of the trading of iron from India to the Middle East by Jewish traders has also been preserved in the Cairo Geniza.[75]

The letters of a Jewish merchant in Aden to a merchant in southwestern India make it clear that Aden was dependent on the import of Indian iron and that some of it was sent onward to the Mediterranean. In these letters there are no less than four types of iron that are mentioned, among which are "refurbished" and "smooth" varieties.[76]

It is noteworthy that the North African, locally produced steel, which Maimonides mentions in his commentary to *Kelim* (above), was called Indian iron. However, according to his description of the processes involved, this was not the crucible steel (wootz) imported from India, but a product that was manufactured by local artisans using one of the techniques of carburization and quenching of bloom iron. It must have been the artisans themselves who named their steel product "Indian iron," presumably to indicate that it was a special type of hardened iron.

CONCLUSION

In our quest to identify references to steelmaking and the use of steel in the classical Judaic sources we have not been disappointed. Although, neither biblical nor rabbinic literature is concerned with providing technological information for its own sake, we found compelling evidence that these important technologies were known.

The biblical references are concise and provide only a limited amount of information. Therefore, we cannot identify the specific types of iron as types of steel. However, we might consider the fact that Biblical Hebrew employs only the word *neḥoshet* (נחשת), without distinction, for both copper and its bronze alloys. Likewise, *barzel* (ברזל), which clearly means iron, was apparently also used for its

[75] S. D. Goitein, "From Aden to India. Specimens of the Correspondence of Indian Traders of the Twelfth Century," *Journal of the Economic and Social History of the Orient*, 23 (1980) 43–66.

[76] S. D. Goitein, *Letters of Medieval Jewish Traders* (Princeton, 1973), p. 187, n. 1 and p. 189. The information in bAZ 16a confirms Goitein's assertion that "Jewish prominence in the metal trade probably went back to some ancient tradition" (p. 18).

carburized varieties, and possibly even for high-grade steel. The fact that the type of iron mentioned in Ezek 27:19, which is presented as a commodity of particular quality, is qualified by the adjectival *ᶜašot*; and the iron mentioned in Jer 15:12, which is described as particularly hard, is distinguished as being from *ṣafon*, means that there was awareness of unusual types of iron.

In postbiblical literature also there is no special word to distinguish iron from its carbon-enriched varieties. Yet there are a number of descriptions of the use of carburized iron and even steel. In bBer 62b and bShab 41a the Greek loan-word *istemaʾ* is used to describe iron hardened by heating and quenching in water. Only carburized iron would harden in response to this treatment. Furthermore, the use of the technique of iron carburization and quenching as a simile for healthy toilet practice (bBer 62b) has to be understood as unique evidence for the common knowledge and significance of this iron working technique in Jewish life at that time.

Another reference (bYom 34b) shows a clear understanding of the way in which properties of iron change after it is heated for a long time in hot charcoal, and that iron becomes hard when quenched in water. The argument between R. Johanan and Resh Lakish in bBm 84a demonstrates that these 3rd-century CE Palestinian sages had a precise understanding of the way in which the properties of iron could be altered, as they differentiated between the processes we call carburization and quenching. The references from mKel 13.4 and tKel BM 1.3 and 3.7 also provide evidence that carbon-enriched (steeled) iron was forge-welded onto the edges of certain types of tools in Palestine during the first centuries of the first millennium.

Since archaeo-metallurgical laboratory research of ancient iron objects is handicapped by advanced corrosion of the iron, which does not leave behind even the "ghost structure" of the metal to help identify the type of iron and the technique used, very few iron objects from excavations in the Middle East have so far been scientifically investigated: literary documentation has thus supplanted the place of laboratory research. The Jewish sources fill the gap between early classical literature and medieval documentation relating to iron and steel technology.

The last section of our paper, devoted to the reference in bAZ 16a, discusses the participation of Jews in the trade of Indian crucible steel. This completes the story that emerges from the literary evidence for steelmaking in the sources. The Israelites of the Bible and Jews of later times were familiar with the technological developments in the use of iron and its carbon-enriched varieties. The biblical references indicate an awareness of the lucrative trade in superior types of iron. In the rabbinic sources, an understanding of the processes involved in the production and use of carburized iron is expressed in discussions concerning the intricate rules of ritual purity, the observance of holy days and other religious and legal matters and customs.