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USE OF COOLANTS AND LUBRICANTS IN HARD MACHINING

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Preliminary notes

Nowadays, the consideration of environmental protection viewpoints is a social obligation in all fields of life. These expectations are even more increased during the manufacturing of machine industrial products, which is why the demand for the reduction of environmental load is becoming predominant in production. This is why the application of used coolants and lubricants (CL) has gained the centre of interest in metal processing procedures. In the development of machining procedures CL contributes not only to the increase of the effectiveness of material removal but it helps to achieve the appropriate accuracy and quality. At the same time coolants and lubricants, depending on their composition, pollute the environment to different extents. That is why it is an emphasized task of technologists in the planning and execution of material removal to reduce the amount of these auxiliary materials, or do without them if possible. In this paper we focus on the determination of the ratios of the consumed CL in alternative procedures of hard machining. By comparative experiments we examine to what extent the consumption of CL can be reduced in the different procedures without any deterioration in accuracy or surface quality of the machined surface/part.

Keywords: *coolants and lubricants, environmentally conscious machining, hard machining*

Primjena rashladnih sredstava i maziva u strojnoj obradi tvrdih površina

Prethodno priopćenje

Danas je stav o zaštiti okoline društvena obaveza u svim područjima života, posebno naglašena u izradi strojno obradivih industrijskih proizvoda. Stoga u proizvodnji zahtjev za smanjenjem zagađenja okoliša postaje sve važniji. Upravo je zbog toga primjena korištenih hladila i maziva (HM) postala od osnovnog značaja u postupcima obrade metala. U razvoju obradnih postupaka HM doprinose ne samo povećanjem učinkovitosti skidanja materijala već pomažu i u postizanju odgovarajuće točnosti i kvalitete. U isto vrijeme hladila i maziva, ovisno o sastavu, različito zagađuju okoliš. Zbog toga je velika obaveza tehnologa da kod planiranja načina otklanjanja materijala i samog postupka, smanje količinu tih pomoćnih materijala, ili ih, ako je moguće, potpuno izbace iz upotrebe. U ovom je radu pažnja usmjerena na određivanje omjera utrošenih HM u alternativnim postupcima obrade tvrdih površina. Usporednim eksperimentima ispitujemo koliko se u različitim postupcima potrošnja HM može reducirati, a da se ne smanji točnost ili kvaliteta obrađivane površine/dijela.

Ključne riječi: *hladila i maziva, strojna obrada koja uzima u obzir zaštitu okoliša, strojna obrada tvrde površine*

1 Introduction

In certain cases the creation of products is insoluble without applying any auxiliary materials, while in other cases it can be solved by low effectiveness. This has been characteristic of machining procedures as well for several decades. In high productivity cutting of steels the cutting zone – depending on the pairing of the cutting tool and workpiece and on the technological conditions – heats to a high temperature. The machining error and the wear speed increases with the temperature. The heating load damages the surface integrity of the product, e.g. by causing tensile residual stress and micro-cracks on the surface and near surface layers, furthermore by quick oxidation and corrosion [1]. For this reason the application of CL is unavoidable in most cases, despite the fact that lots of dry cutting experiments were performed. However, with all performance dry cutting is not adequate for high precision machining. Its function is cooling, lubrication and chip removal.

In appropriate application of CL [2], it

- favourably influences the tribological processes taking place in machining,
- aids material removal (reducing cutting force and cutting temperature),
- reduces tool wear and increases tool life,
- improves the machined surface quality,
- increases process reliability,
- reduces the times of machining,
- increases producibility,
- reduces the vibration sensibility of the machining system, etc.

Because of these advantages the use of CL has greatly increased, many times exceeding the growth of the machine industry in the world.

Let us illustrate this growth with some data. In the middle of the 1990s the use of CL in Germany was about 88,9 million litres (23,5 million gallons US) per year [3]. In this interval about 378 million litres (≈100 million gallons) of metal working oil were used in the USA, according to estimations [4], and the estimated amount of emulsion used was on a similar order of magnitude [4]. On the enterprise level the character of the production determines the quantity of used CL. In a typical large car factory metal works machine stock uses 2,3 million litres (≈608 000 gallons) per year of concentrates of metal working fluid and more than 1,2 million litres (≈317 000 gallons) of straight oil [5].

In 1998 about 2300 million litres (607,6 million gallons) of CL was used for machining operations in the world. The greater part was used in North America; Asia followed, and Europe was the third [6]. In the markets of the USA the total amount of CL in metal working in 2002 was estimated at 933,4 million litres (246,6 million gallons) out of which 443,6 million litres (117,2 million gallons) were metal removal fluids. Its distribution by fluid: 103,3 million litres (27,3 million gallons) of straight oils; 186,6 million litres (49,3 million gallons) of soluble oils; 82,1 million litres (21,7 million gallons) of semi-synthetics; 71,5 million litres (18,9 million gallons) of synthetics [7]. According to the Association of European

Lubricant Manufacturers, in 2005 the amount of liquid which helps metal working was about 317,9 million litres (84 million gallons) in the European Union [8]. In Japan the used amount of CL in 2008 (which responds to the use of the year 1984) was as follows [4]. The distribution of consumption of coolants and lubricants: 100 million litres (26,4 million gallons) of CL liquid non-soluble with water (cost of disposal is 35 ÷ 50 yen/litre); 50 million litres (13,2 million gallons) of chlorine-free water-soluble CL liquid (cost of disposal is 300 yen/litre); and 10 million litres (2,64 million gallons) of water-soluble CL liquid containing chlorine (cost of disposal is 2,250 yen/litre). The data were supplied by the Japan Metalworking Oil and Coolant Association and Nisseki Mitsubishi [4].

Besides the volume of consumption of CL its effectiveness has been examined continuously. So, the methods of how the CL was delivered to the working area and to the interface of tool/workpiece [9] [10], or the effects of additives were examined [11]. Examinations have been accelerated by the fact that, despite their certain advantages, the disadvantage of CL using was more emphasized as shown in Fig. 1 [12].

The pollution of the environment increases the cost of production as well as damaging the worker's health. Improperly treated coolants and lubricants that support machining, damage the environment (soil, water resources, etc.) [12]. In the machining workshop CL substances have harmful effects on the health of workers (machine operators), causing primarily epidermis and respiratory problems [13, 14, 15].

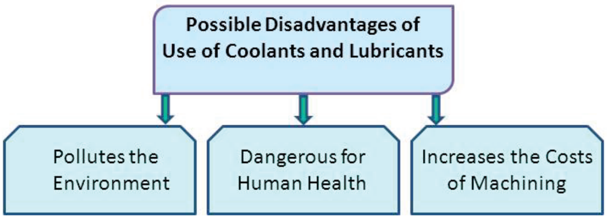

Figure 1 Disadvantages of the use of Coolants and Lubricants

If we look at the cost of production in more detail, partial costs with CL can be divided into two parts. One part is the purchasing cost of liquids, while the moderation and disposal cost of injurious materials is the other part. In the mid-1990s in Germany the purchasing and disposal cost of coolants and lubricants was about 1 billon German marks [16]. According to estimations in the USA the cost of buying and destroying of cutting supporting liquid was about 48×10^9 USD per year in the same period [17]. For 1998, the cost of the applied coolants and lubricants was approximately $2{,}75\times10^9$ USD [6]. In Japan in 2008, according to the publication of Lubricant Economy, the purchasing cost of coolants and lubricants was about 29×10^9 Japanese yen. According to Feng et al. [4] the disposal cost of coolants and lubricants was 42×10^9 yen, while the total cost of purchasing and disposal was about 71×10^9 yen [4].

The costs of metal working fluids have been estimated in many different ways by metal working societies. According to the estimation of tool coatings producer Balzers Company, (head-quartered in Amherst, New York) the cost of metal working fluid makes up 16 % of the total expenses of a typical end user, as can be seen in Fig. 2 [18]. By contrast, according to Doug Hunsicker, a member of the Society of Tribologists and Lubrication Engineers and the retired chief engineer of Caterpillar (Peoria, Illinois), the costs of metalworking fluids made up 0,9 % of the total production costs in 2001 [18].

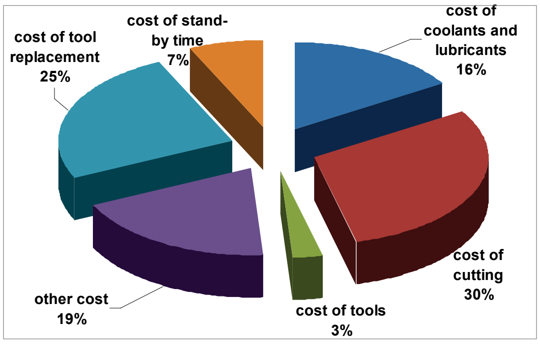

Figure 2 Typical End-User Manufacturing Costs [18]

Besides those mentioned before, there are scientists [3] who conclude that the cost of liquids supporting machining forms a significant part of the total manufacturing cost and they estimate that this cost is equal to or even higher than the cost of cutting tools. Because of all of these negative effects of costs and application the fundamental interest of the producers applying CL is to minimize the costs, which may even exceed the cost of cutting tools.

2 Possibilities of cooling and lubrication to reduce the environmental load

As a result of developments two main directions have been emerged in order to come into being to realize a lower environmental load of cooling and lubrication: the first consists in changing the composition of coolants and lubricants while the second focuses on reducing their volume as shown in Fig. 3.

- In the course of the change of composition, synthetic liquids (pure synthetics and semi-synthetics) or biodegradable natural oils (e.g. vegetable oils) can be applied instead of liquids containing mineral oil. The synthetic-base oils – synthetic hydrocarbons, fatty alcohols, poly-glycols, and esters – are gaining in significance. Due to their homogeneous polar molecule structure, they provide the possibility to produce predefined physical and mechanical properties repeatedly. A further advantage of synthetic-base materials is their high viscosity, in addition to their environment-friendly nature and biodegradability [2].
- In the course of reduction (minimization) of the volume of coolants and lubricants the volume of supplied coolants and lubricants is reduced to a minimum volume which almost disappears during the machining process, through evaporation or by sticking to the chips. The chip, cutting tool and workpiece remain "quasi dry" and there is no necessity for further after-treatment. The chips can be directly passed for re-use. That is why we are speaking about evaporating lubricant or exhausted lubrication.

- At minimum quantity lubrication the volume of coolants and lubricants is 10 ÷ 100 ml/h. The cooling effect is insignificant and the washing effect is invalid.
- In the course of minimum quantity cooling the cooling effect is dominant and performed mostly by compressed air, or a mixture of air and water or air and emulsion. Its use is reasonable when the heat occurring during machining can cause harmful alterations to the workpiece, cutting tool or machine tool; for example, when there is adhesion in the cutting tool/chip interface or when enormous cutting tool wear would arise in dry machining [19].
- High efficiency (high heat strength and wear resistance) cutting tools make the successful completion of dry machining operations possible.

These methods can only be suggested and applied effectively in cases when the machining can be realized without the deterioration of the cutting performance and/or the quality of the machined surface.

3 Dry machining

In the machine industry manufacturing processes the application of dry machining is the most effective method for reducing the environmental harm in connection with cooling and lubrication, because obviously all negative effects caused by CL can be terminated. So the main advantages of dry machining [19] are that:

- there is no air pollution or water pollution, so it is environmentally friendly,
- there are no coolants and lubricants, so they do not cause allergic diseases in ancillary workers; it is not injurious for health,
- production costs are reduced, since
  - the purchasing and treating cost of basis material and additives is omitted,
  - the cleaning ("recycling") and related costs of coolants and chips are omitted.

At the same time the substitution of the roles of coolants and lubricants in dry machining is indeed a major challenge. The conditions of manufacturing (technological conditions) are to be planned in a way that the lack of the tasks fulfilled by coolants and lubricants – lubrication of cutting tool and workpiece, reduction of heat in the cutting zone, corrosion prevention of the workpiece, cleaning of the workpiece and washing away the chips from the place of cutting – does not cause any disadvantage, or as small as possible, in terms of economic efficiency or quality related to the previously used procedures.

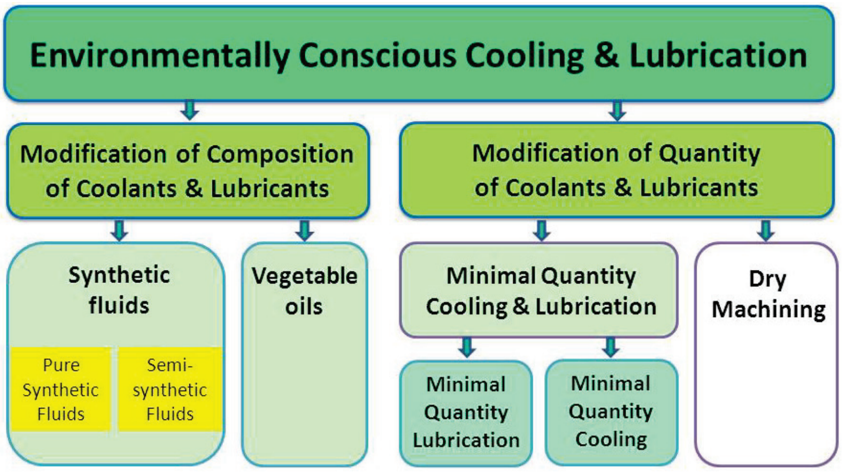

Figure 3 Main possibilities of realisation of environmentally conscious cooling and lubrication

If we simply neglect the use of coolants and lubricants without changing the technology, the conditions of material removal may deteriorate expressively. The absence of coolants and lubricants can lead to increased friction and this produces unacceptable large temperature values. The cutting tool can wear more rapidly, a built-up edge can occur on the cutting tool which can have an effect on the surface roughness of the workpiece, and the residual stress of the workpiece can increase. The absence of the active removal of chips from the cutting zone can lead to an increase in temperature, chipping off cutting edge, or even tool breakage. That is why the application of dry machining is fruitful only when the cutting tool-workpiece pairing is appropriate and the technological conditions are properly chosen [20].

In dry cutting special tooling was developed in order to substitute the missing lubrication and to solve the chip wiping off. First of all, tool materials are used which have high hardness at high temperatures and good wear resistance. Individual tooling can be made by further developing tool geometry, which can realise the functions of chip guiding and chip breaking, assisting the chip clear-away function. In addition, vacuum and compressed air systems can remove chips from the cutting environment.

Operational conditions and materials producing short chips, small cutting force and low temperature are the most suitable for dry machining with single-point cutting tools. However, dry grinding, honing and lapping mean great challenges [21]. The most important factors to be taken into account in the application of economic dry machining are summarised in Fig. 4 [22].

4 Experimental conditions

The aim of the experiments was the examination of the machining of parts having hard surfaces with different procedures. We worked with technological conditions and cutting parameters by which the material removal tasks can be solved in accordance with the prescribed data**.** The experiments were made for a hole of a steering lock adapter. The accuracy of the machined surface was IT7 and the surface roughness was Rz = 10 μm. Tab. 1 summarizes the labels and descriptions of the procedures investigated while Fig. 5 contains the draft of the workpiece. The 26,07 mm diameter hole was machined only at a length of 36,5 mm with the examined procedures proposed by the present investigation.

Figure 4 Parameters affecting dry machining

The data of the workpiece were as follows: material: 16MnCr5; hardness: 61 ÷ 63 HRC; length of bore: 36,5 mm; ℓ/d relationship: 1,4; allowance: 0,3 mm; sequence size: n = 200. Tab. 2 illustrates the technological parameters of the different versions.

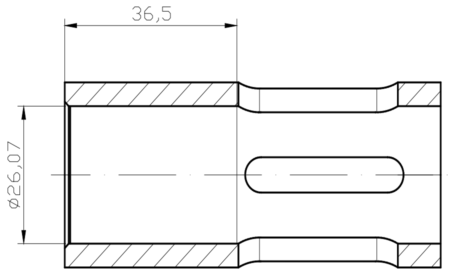

Figure 5 Draft of the workpiece (steering lock adapter)

The manufacturing was carried out in three ways: grinding with coolants and lubricants, hard turning procedures without any coolants or lubricants, and in the third case by the combination of the previous two procedures. The technological parameters were chosen so that the prescribed roughness and accuracy were to be ensured for all procedures. Applied procedures:
G – grinding,
B1, B2 – hard boring,
C1, C2 – combined procedures.

Applied cutting tools:

In hard boring we used two carbide inserts which were labelled Insert 1 (4NC–CNGA120408TA2) and Insert 2 (4NC–CNGA120408GSW2) and the hard borings executed by them were labelled B1 or B2.

In the combined procedure, similarly to hard turning, the indicated two procedures differ by the applied inserts. Roughing is done in the C1 procedure with Insert 1, while in C2 with Insert 2. For smoothing the same grinding wheel (Corundum wheel: 40×20×16-9A80-K7V22) is used.

Table 1 Hard boring procedures applied in the experiments

Process		Internal traverse grinding	Hard boring		Combined procedure		
Sign		**G**	**B1**	**B2**		**C1**	**C2**
Procedure	Roughing	Corundum wheel	Single point cutting tool: Carbide Insert 1	Carbide Insert 2	Hard boring	Carbide Insert 1	Carbide Insert 2
	Smoothing			Carbide Insert 1	Internal infeed grinding	Corundum wheel	
Machine tool		SI-4/A	PITTLER PVSL-2		EMAG VSC 400 DS		

Table 2 Technological conditions of the different versions

Process		Internal traverse grinding	Hard boring		Combined procedure		
Sign		**G**	**B1**	**B2**		**C1**	**C2**
Procedure	Roughing	v_c= 30 m/s v_w = 13 m/min $a_{e,R}$ = 0,02 mm $v_{f,R}$=2200 mm/min	v_c = 180 m/min $a_{p,R}$ = 0,1 mm f_R= 0,15 mm/rev	v_c = 180 m/min $a_{p,R}$ = 0,1 mm f_R = 0,24 mm/rev	Hard boring	v_c = 180 m/min $a_{p,R}$ = 0,1 mm f_R=0,15 mm/rev	v_c = 180 m/min $a_{p,R}$ = 0,1 mm f_R=0,24 mm/rev
	Smoothing	v_c = 30 m/s v_w = 13 m/min $a_{e,S}$= 0,001 mm $v_{f,S}$=2000 mm/min	v_c = 180 m/min $a_{p,S}$ = 0,05 mm f_S= 0,08 mm/rev	v_c = 180 m/min $a_{p,S}$ = 0,05 mm f_S = 0,12 mm/rev	Internal infeed grinding	v_c = 45 m/s v_w = 13 m/min $v_{f,R}$ = 0,0050 mm/s $v_{f,S}$ = 0,0036 mm/s	

5 Application of CL in the process of material removal

In the examined hard machining procedures the amount of used up coolants and lubricants are determined by the CL demand in grinding and hard turning since all the other procedures are the combination of these two. In grinding, the removal of the allowance demands a high quantity of coolants and lubricants [23]. For that reason this procedure pollutes the environment to a great extent, damages workers' health, and the used up auxiliary materials increase the expenditure of the procedure.

In hard turning the application of CL is not needed to remove the chips efficiently [22]. Furthermore, the byproducts created during cutting are less polluting for the environment and are easily recycled. Therefore, from the point of view of ecology hard turning is the most beneficial version of hard machining. In a combined procedure the proportion of time spent on turning and grinding provides the extent of CL consumption. The reason is that in the combined procedure the roughing is done dry (turning), while the smoothing (grinding) is done with coolants and lubricants. In the combined procedure we use a machine tool in which parts are machined on one clamping.

First we examined how much coolant and lubricant is consumed by different companies machining with cutting parameters that produce components with the same accuracy and surface roughness. As described before, the consumption of coolants and lubricants is proportional to the time spent on grinding. The procedure entirely demanding coolants and lubricants (grinding) is 100 %, while cutting done dry is 0 %. In the other machining versions we demonstrate what the proportion of the time of grinding is in each procedure within the operation time.

The evaluation happened after machining sequence size of 200 pieces three times. First we determined the operation time of the procedures. While in grinding the surface was machined nearly four minutes (Fig. 6) until then with the other procedures during 0,6 ÷ 1 min.

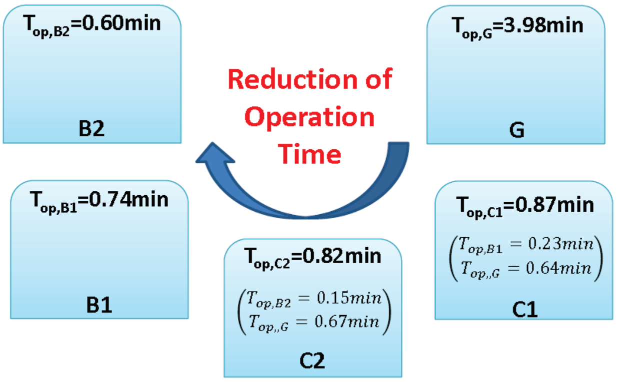

Figure 6 Operation times in different procedures

The operation time significantly decreases compared to grinding, when applying the other procedures the sequence is C1, C2, B1, B2 with the decrease of time. The operation time of operation B2 is only one-sixth that of grinding. In Fig. 7 we demonstrate what percentage of CL is used in the different procedures, projected on the operation time needed for the machining of a hole. It can be seen that in combined procedures it is not necessary to use CL during the whole operation time, rather for 81,7 ÷ 73,6 % of it. This 18,3 ÷ 26,4 % reduction in the operation time does not seem to be meaningful, but the substantial differences in operation time are significant in real application (Fig. 8). Taking this into account, too, it can be seen that the hole with the given dimension, precision and roughness can be machined using hard turning, and realizing by this a CL consumption that is reduced to 16,0 ÷ 16,8 % in comparison with the classical grinding procedure.

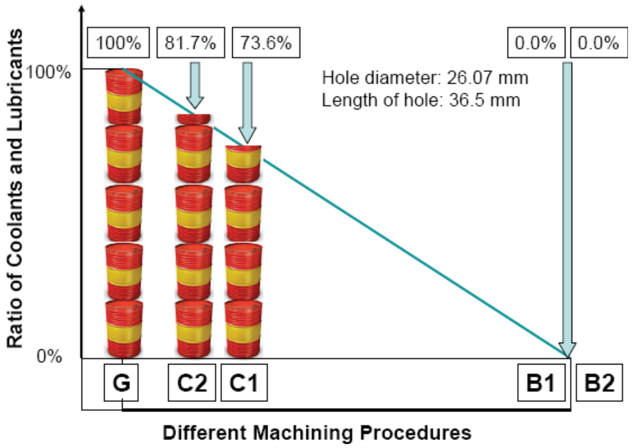

Figure 7 The proportion of the use of coolants and lubricants in operation time in the different procedures

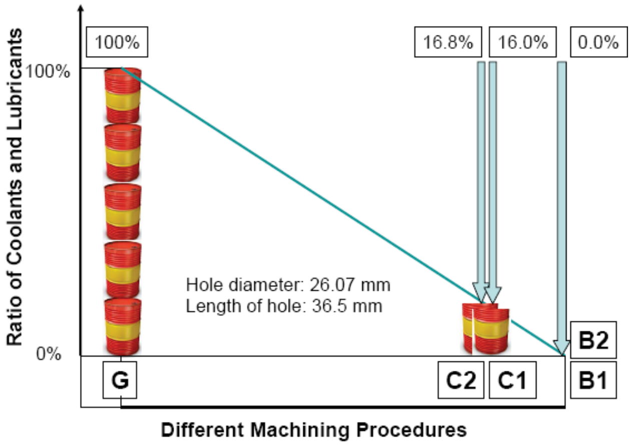

Figure 8 The proportion of environmental load in different procedures related to grinding

6 Conclusions

For a long time the machining of hard surfaces of parts was possible only with the use of high volume of coolants and lubricants, since only an abrasive procedure, primarily grinding, was used for this task (operation).

Now, instead of the grinding generally applied before, the application of either hard turning or a combined procedure can be suggested for finishing the bore holes of disc-type components.

Because of the significantly higher material removal rate and the shorter machining time, hard turning is a remarkably more productive and economic procedure. When the machining with single-point cutting tools became technically possible, in the case of some components not only the conditions for more effective chip removal but the condition for the reduction of the environmental load was created as well. As the operation can be carried out dry, the environmental burden caused by CL consumption can be avoided. Thus, by applying hard turning, a rarely achieved technical-engineering objective is met: the environmental load can be decreased while gaining economic benefits.

At present, in most cases the technical and technological conditions are provided for hard turning to substitute grinding as a more effective procedure. There are, however, components for which the operational conditions demand ground topography. In such a case the application of the so-called combined (hybrid) machining is suggested. In the combined procedure we still use grinding; however, generating ground surfaces requires substantially less CL than the procedures used earlier. The extent of the reduction is impressive: its value is over 80 %.

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